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FINAL REPORT

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THE IMPACT OF BUILDING CODE CRITERIA AND EMERGENCY PREPAREDNESS CRITERIA ON WATER DEMAND REQUIREMENTS TO FIRE PROTECTION

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Prepared for:
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By: Department of Fire Protection Engineering
College of Engineering
University of Maryland
College Park, Maryland 20742

THE IMPACT OF BUILDING CODE CRITERIA
AND
EMERGENCY PREPAREDNESS CRITERIA
ON
WATER DEMAND REQUIREMENTS TO FIRE PROTECTION

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method derived from theoretically and empirically based concepts. These methods are compared and contrasted relative to the model building code and civil preparedness criteria. The water supply requirements for domestic usage are calculated by an existing technique, the results of which are compared to the fire protection related water demand. Because of the conclusions and limitations noted in this study relative to the concept of water demand requirements in the event of crisis relocation, several areas are identified which future research endeavors should consider.

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I. INTRODUCTION

1.1 Problem and Scope

Experience has indicated that "water is nature's answer to the problem of controlling and extinguishing fire - it is universal" (1, p. 19). However, fire fighters, fire protection engineers, building officials, fire suppression equipment personnel, civil preparedness personnel and insurance company representatives appear to disagree on the requirements for the adequacy and application rates of water for fire extinguishment. This disagreement is evidenced by the multitude of published standards or criteria for determining water supply requirements for routine fire suppression operations and operations in natural, civil disturbance, or national emergencies.

Water supply for fire protection is usually expressed as the quantity of water required to extinguish a fire, control a fire to the place of origin, or to provide exposure protection (2). The application of water to achieve one or a combination of these objectives includes hose streams and/or automatic water base suppression systems. In addition to the base water demand requirement, consideration must also be given to the rate of flow and the duration of flow for specific problem situations.

One literature source indicates that the quantity and duration of water supply for the protection of buildings and structures considers the variables of construction, heights, areas, occupancy fuel load and exposure factors (3). These variables represent basic considerations in building codes, published standards, ordinances and emergency preparedness documents. It follows that

*Numbers refer to references noted at the end of this report.

the building codes, standards, and special civil preparedness criteria have both a direct and indirect impact on water supply requirements for fire protection. This relationship is not specifically documented in the literature, nor is the scope and specificity of the different criteria clearly understood. Furthermore, a comparative analysis of water supply requirements between building codes and special civil preparedness criteria does not appear in the literature.

This study evaluates water supply demand requirements for buildings and structures with special reference to both building code criteria and civil preparedness criteria. The following study phases outline a systematic approach to thoroughly examining water discharge rates and water supply duration for meeting the alternative fire safety objectives of: 1) fire control, 2) fire extinguishment, and 3) exposure control.

1.2 Research Plan

This study is divided into six phases. Each of these phases are presented in this report in an individual section with the exception of Phases I and VI which were combined for the purposes of this presentation only. The six phases are briefly described below:

Phase I: 16 occupancies and complexes are selected for comparative study purposes. An appropriate hypothetical building or complex for each is suggested.

Phase II: A theoretical approach to fire flow requirements is considered. The heat transfer characteristics of water is presented relative to its fire suppression capability for fires in structures involving predicted rates of heat release of ordinary combustible materials.

Phase III: Existing techniques for calculating fire flow requirements are identified with the background of each technique briefly described. Four of the more appropriate techniques are suggested for further examination.

Phase IV: Water supply requirements for domestic use and fire protection needs are evaluated considering the conditions of crisis relocation on a potential host community. Potential sewer capacity requirements are also addressed.

Phase V: Model building code regulations are applied to the selected occupancy and complex types relative to general requirements pertaining to maximum height and areas, etc. Methodologies for fire fire flow and domestic use requirements are presented and compared for the largest buildings permitted by the model building codes.

Phase VI: Fire flow and domestic use requirements are applied for the hypothetical buildings proposed in Phase I Water supply requirements for domestic use are compared to those relative to fire protection.

II. Theoretical Calculation Approach for Determination of Fire Flow

2.1. Introduction

The objective of this phase of the study is to develop a theoretically based method to calculate the fire flow required to control an assumed compartment fire. This approach considers the thermal characteristics and heat transfer mechanisms of the compartment, the extinguishing agent and the fire.

2.1.1. Considerations of Approach

Fire flow is defined for this study as the rate of water which must be applied on a fire in a compartment to achieve control. For this project, the criteria for the achievement of control are:

1) Total absorption of the heat release rate from the fire by the water application rate and

2) Reduction of the upper room air temperature to 400°F.

Complete absorption of the heat release rate from the fire results in the loss of a primary energy source delivering heat to the available fuel for combustion. However, even with the elimination of the main energy source, a substantial amount of energy may be stored by the heated air within the compartment. This energy could be delivered to the available fuel to sustain combustion. Thus, the second criterion is included, which considers that the air within the compartment will be cooled to the extent that the air will not be capable of delivering sufficient heat to sustain combustion. The specific temperature of 400°F was subjectively selected with the justification being that the ignition temperature of most cellulosic fuels is in the vicinity of 400°F. These two criteria chosen to describe control conceptually agree with those selected by Ball & Pietrzak (4).

2.1.2. Limitations and Assumptions

Some major constraints on the formulation of this approach relate to the utility and applicability of the approach. The potential user of the technique may have a limited knowledge in fire protection or have low analytical skills. Further, the method should not require a large expenditure of effort or a great deal of training as a prerequisite for use. The proposed technique must be applicable for a wide range of occupancies, whether in the planning stage or after being occupied.

Due to these constraints several assumptions are required to simplify the technique and to assure general applicability. These assumptions are listed below:

1. Combustion of the fuel is assumed to occur with the reactants combining stoichiometrically. (see section 2.2.3)
2. The quantity, $\frac{\Delta Hc}{r}$, is assumed to be 1,500 Btu/lb. (see section 2.2.4)
3. The compartment fire is in the primary burning stage. (see section 2.2.4)
4. The upper room air temperature is uniform. (see section 2.2.7)
5. The emissivity of the room is uniform as are other heat transfer parameters for the room. (see section 2.2.7)
6. The emissivity of the flame is 1.0 and the area outside the compartment behaves similar to a black body. (see section 2.2.7)
7. The flames fill the entire room. (see section 2.2.7)
8. Sixty-seven percent of the applied water reaches the vicinity of the fire and 75 percent of that evaporates. (see section 2.3.2)
9. The heat loss required to cool the upper room air temperature to 400°F is negligible compared to the heat release rate for fuel controlled fires. (see section 2.4)

2.2. The Potential Fire

Examination of the potential fire is divided into two areas. The first area consists of a review of the fundamentals of combustion. This review is followed by a discussion of the interaction between the fire and the compartment.

2.2.1. Fundamentals of Combustion

The combustion of any fuel is simply an oxidation reaction. The combustion process of wood has been extensively studied, as reported by Harmathy (5), Thomas, Heselden and Law (6) and Quintiere (7). The reaction of wood and oxygen is represented by the following chemical equation, as presented by Babrauskas (8).

$$C_{.32} H_{.46} O_{.22} + 0.32\ (O_2 + 3.77\ N_2) \rightarrow 0.32\ CO_2 + 0.23\ H_2O + 1.21\ N_2$$

Mixing wood and oxygen obviously does not guarantee combustion. Cellulosic fuels must be heated sufficiently to release flammable vapors before combustion occurs. This process is termed pyrolysis, which is similar to "cracking" or breaking the cellulose molecule into other hydro-carbons for combustion. The amount of heat required for this process is labelled the "heat of pyrolysis."

This initial amount of heat has been addressed by Rasbash in his fire point theory for solids (9), which is analogous to flash points for liquid fuels. The quantity of heat required is dependent on the material thermodynamic and heat transfer properties of the fuel.

Heat Released by Combustion

The heat of combustion is the amount of energy released by unit mass of the fuel undergoing "perfect burning." One important consideration is the percentage of the total heat of combustion released through combustion of the material. If a material is perfectly burned, then the percentage of the total heat of combustion which is released would be 100 percent. The reaction would be perfectly efficient and only occurs if the reactants are exactly mixed in the proper or stoichiometric ratio (according to the chemical equation).

From empirical evidence presented by Kawagoe (10), Beyler has determined that even with the proper ratio, the heat released is only about 68 percent of the heat of combustion (11). This low percentage of energy released is attributable to poor mixing of the air and flammable vapors.

A classical view of combustion theorizes that the heat released by the fire is fed back to pyrolyze virgin fuel. This has been demonstrated by Rasbash (9) among others for solid fuels, Bullen (12) for plastics and traditionally for liquid fuels (5). However, Harmathy (5) discusses an apparent discrepancy for the case of wood. Harmathy's disagreement with the heat feedback concept is appropriate for a portion of partially charred wood, but does not appear to be appropriate for a new, uncharred segment of wood. Thus, this heat feedback theory is considered appropriate for the general case, e.g. liquid and solid fuels, including previously uncharred, unpyrolyzed wood.

2.2.2. Interaction of the Fire and the Compartment

The compartment plays an important role in the heat feedback cycle, with the heat generated by the fire being returned to the fuel by means of convection or radiation. Convection is dominant in horizontally transporting energy from nearby flames to new fuel, according to Rasbash (9) and Corlett and Williams (13). Radiation from the flames heats the air in the enclosure and the walls of the compartment in addition to unburnt fuel, which in turn reradiate energy back to the fuel, as shown by Quintiere (7). More importantly, the compartment regulates the amount of air which the fire receives for continuing the combustion process. The amount of air delivered to the fuel is a key factor in determining the heat release rate by the fire.

Ventilation Controlled Fires

An insufficient quantity of air inflow causes the fire to be "ventilation controlled," in which case the rate of burning is directly influenced by the air flow delivered to the fire, according to Thomas and Nilsson (14). A ventilation controlled fire, which cannot burn perfectly because of the insufficient air, releases partially-oxidized combustion products, such as carbon monoxide. Because of the insufficient air flow, the upper room air temperature can be expected to be higher, as less air is available to act as a convective medium for cooling (15).

Fuel Controlled Fires

A fuel controlled fire results if an adequate or greater than adequate supply of air flow is delivered to the vicinity of the fuel. In this case, the rate of burning is directly influenced by the fuel type and geometry (14). Visich showed that compartments with fuel controlled fires tend to have lower air temperatures since the air supply is greater for cooling than that for ventilation controlled fires (16).

2.2.3. Determination of Control Mechanism of Fire

A recent method by Coulbert (17) for distinguishing between ventilation and fuel controlled fires examines five Relative Energy Release Criteria. Through an investigation of these criteria (specifically the fuel surface area and ventilation criteria) the more dominant criterion can be determined, thereby concluding that the fire is ventilation or fuel controlled. However, this technique is still in a developmental stage.

Harmathy (5) presents a more traditional approach for distinguishing between fuel and ventilation controlled compartment fires. This is performed through an investigation of the ventilation parameter, ϕ. This parameter is determined by the following relation:

$$\phi = 60\ \rho_a\ g^{1/2}\ A_w\ h_w^{1/2}$$

where $\rho_a = 0.081\ \text{lb/ft}^3$

Substituting for ρ_a and g,

$$\phi = 27.5\ A_w\ h_w^{1/2} \qquad [1]$$

Equation [1] is applicable for any compartment with one ventilation opening. If multiple openings are present, then the proper equation is:

$$\phi = 27.5 \sum_{i=1}^{n} A_{wi}\ h_{wi}^{1/2}$$

where n is the total number of openings in the compartment.

The exposed surface area of the fuel, A_f, within the compartment must be

determined. After calculating ϕ and A_f, the fire is determined to be fuel controlled if:

$$\frac{\phi}{A_f} \geq 3.22$$

In this case, the rate of burning is evaluated by the following relation:

$$R = .076\ A_f \qquad [2]$$

The compartment fire is determined to be ventilation controlled if:

$$\frac{\phi}{A_f} < 3.22$$

In which case R is given by:

$$R = .0236\ \phi \qquad [3]$$

Substituting for ϕ from equation [1],

$$R = .649\ A_w\ h_w^{1/2} \qquad [4]$$

This quantity is the English-unit equivalent of Kawagoe's findings (17):

$$R = 330\ A_w\ h_w^{1/2}$$

It should be noted that Harmathy indicated that the division between ventilation and fuel control may not be distinct, rather is separated by a region described by:

$$2.88 < \frac{\phi}{A_f} < 3.55$$

Within this range, fires may be either ventilation or fuel controlled. Subsequent studies should compare the resulting rates of heat release for ventilation control and fuel controlled fires with identical $\frac{\phi}{A_f}$ ratios. It may be desirable to pessimize the results within this range by selecting the control mechanism yielding the higher heat release rate, which in turn will require a higher fire flow.

Babrauskas defines the heat release rate from combustion proceeding stoichiometrically as:

$$\dot{q}_F = \dot{m}_a \left(\frac{\Delta Hc}{r}\right) \qquad [5]$$

where $m_a = 3.70\ A_w \sqrt{h_w}$ from Kawagoe's work (10).

The variable, r, is defined from the chemical equation as being the amount of mass of air to be combined with a unit mass of fuel for stoichiometric combustion, as given below:

1 lb. fuel + r lb. air → (1 + r) lb. products.

The rate of burning R, and the air inflow, m_a, are related by:

$$\frac{r}{\eta} \dot{m}_a = R$$

Where η is the ratio of the actual fuel to air ratio to the stoichiometrically defined fuel to air ratio. For wood, $\frac{r}{\eta} = 5.7$ and is dependent on the fuel, as is the heat of combustion, ΔH_c. However, examination of Table 2.1 indicates that $\left(\frac{\Delta Hc}{r}\right)$ is basically independent of the fuel.

Babrauskas also states that the highest room temperatures and total heat generated are present if combustion takes place near stoichiometry. Thus, for ventilation control fires, equation [5] is suggested for use, which assumes stoichiometric combustion. This assumption greatly simplifies the expression for heat release rate and also incorporates a factor of safety by assuming the most severe case.

Table 2.1 Fuel Combustion Properties (5, p.41)

Fuel	ΔH_c (Btu/lb fuel)	$\frac{\Delta H_c}{r}$ (Btu/lb air)	$\frac{r}{\eta}$
Wood	8,460	1,475	5.7
Polyethylene	19,800	1,370	14.5
Polystyrene	18,000	1,370	13.1
Polyurethane	10,260	1,385	7.4

2.2.4. Rate of Heat Release - Ventilation Controlled Fires

Using Equation [5] and substituting for $\dot{m}_a$, the equation for the heat release rate for a ventilation controlled fire is:

$$\dot{q}_F = (3.7 A_w \sqrt{h_w})\ 1500. \qquad [6]$$

The value of 1,500 Btu/lb-air for $\left(\frac{\Delta H_c}{r}\right)$ is selected to pessimize the results. Equation [6] becomes:

$$\dot{q}_F = 5550\, A_w \sqrt{h_w} \qquad [7]$$

Examination of this equation indicates that the rate of heat release is independent of the fuel. Beyler (11) indicates that the quantity $\frac{\Delta H_c}{r}$ is independent of the moisture content (in the case of wood) and also of the efficiency of combustion. This latter conclusion indicates that the assumption of stoichiometric burning actually is of limited consequence.

There are two principal stages of a ventilation controlled compartment fire, as suggested and described by Harmathy (5). The primary stage is that stage after which the fire has become self-sustaining and is characterized by a constant heat release rate. The primary stage continues until approximately 70 percent of the fuel has been consumed. The secondary stage follows, in which the heat release rate slowly decreases to near zero. The primary stage has the highest rate of heat release and thus will be assumed to be the stage in which extinguishment is attempted. As is discussed later, the fire flow is directly proportional to the heat release rate thus by selecting the highest possible value another conservative assumption is made.

The constant rate of heat release observation agrees with the work by Coulbert (17). Pettersson (18) verified that the burning rate equation (equation [4]) is accurate for most engineering applications.

2.2.5. Rate of Heat Release - Fuel Controlled Fires

The heat release rate for a fuel controlled compartment fire is given by:

$$\dot{q}_F = R(\Delta H_c) \qquad [8]$$

Substituting R from equation [2]

$$\dot{q}_F = (.076\, A_f)(\Delta H_c) = 610\, (\gamma)\, A_f \qquad [9]$$

This equation is fuel dependent and is also more tedious to utilize as calculation of the surface area of the fuel, A_f, and fuel composition factor, γ, may be tedious.

The fuel composition factor is related to the percentage of the fuel which

is non-cellulosic. If all of the fuel in the compartment is cellulosic, γ is 1.0. If the fuel is not solely cellulosic, then γ is used to evaluate an average heat of combustion for the space. For example, if half of the fuel is synthetic with a heat of combustion of 16,000 Btu/lb and half is cellulosic (heat of combustion of 8,000 Btu/lb), then γ is:

$$\gamma = \frac{\frac{1}{2}(16{,}000) + (8{,}000)}{8{,}000} = 1.5$$

The use of this factor assumes that non-cellulosics burn at the same rate as cellulosics. This has been shown not to be totally valid (12) however, some approximation technique is necessary to evaluate a rate of heat release for the compartment for this study. As an approximation, the averaging technique utilizing the fuel composition factor is considered to be valid. However, due to the lack of general validity, this procedure should be avoided if possible by assuming $\gamma = 1.0$. This assumption is recommended in instances where a majority of the fuel in the compartment is cellulosic.

2.2.6. Energy Balance Equation

The energy balance for a compartment fire is given by Kawagoe (19) as:

$$\dot{q} = \dot{Q}_I + \dot{Q}_R + \dot{Q}_L + \dot{Q}_a + \dot{Q}_H \qquad [10]$$

where

$\dot{Q}_H$ = heat release rate of fire in room

$\dot{Q}_I$ = rate of heat loss by heat transfer to interior surfaces

$\dot{Q}_R$ = rate of heat loss by radiation through openings to outside air

$\dot{Q}_L$ = rate of heat loss by convection through openings to outside air

$\dot{Q}_a$ = rate of heat loss to warm enclosure air

This equation is examined to obtain a better understanding of the key parameters affecting the fire and its extinguishment. This equation is useful to study the importance of the upper room air temperature. A lower air temperature results in a lower rate of burning, according to the energy feedback theory.

$\dot{Q}_I$ is dependent on the heat transfer properties of the wall. Walls with

high absorptivity of radiation and conductance are capable of absorbing and dissipating heat quickly. Kawagoe and Sekine (10) observed that the enclosure material properties are very influential on the air temperature within the room, e.g. Bullen (12) notes that if the wall is capable of absorbing and rapidly diffusing heat, the air temperature may be cooler and rate of burning less. Visich (16) states that this quantity of heat loss rate ($\dot{Q}_I$) is substantially smaller than $\dot{Q}_R$.

$\dot{Q}_R$ is dependent on the size of the openings in the compartment, as is $\dot{Q}_L$. If the compartment has no openings, then these terms obviously will be zero. Conversely, if the openings are very large, then heat losses due to radiation and convection to outside is substantial. $\dot{Q}_R$ is discussed in a later section relative to exposure hazards.

The heat required to warm the enclosure air has been observed by Coulbert (16) to be small except in the early stages of the fire. Once again, if the ventilation rate is high, then cool air is constantly drawn into the warm enclosure and is heated. Conversely, minimal ventilation introduces little cool air and minimal heat is expended to warm this air.

Thus the energy equation (equation [10]) is influenced by several factors related to the compartment. Bullen (20) found that the geometry of the compartment can be a significant factor, since most of the previously conducted studies consider a near-cubical compartment. The ventilation openings of the compartment and heat transfer properties of the enclosure also affect the equation.

2.2.7. Upper Room Air Temperature

The upper room air is defined as the air occupying the space in the upper half of the compartment. Quintiere (7) and Visich (15) agree that the temperature in this region of a room can be considered uniform. This assumption is valid for a quasi-steady thermal process and in the case where no combustion occurs in this region (7, p. 147).

Kawagoe and Sekine (17) conducted an extensive study to evaluate the fire temperature in a compartment. In that effort, these three assumptions were made:

1. The temperature in the compartment and emissivity of materials within the compartment are uniform.

2. The emissivity of the flame is 1.0 and the flame occupies the entire volume of the room.

3. The emissivity of the region outside the compartment openings is equivalent to that of a black body.

These assumptions are not unusual for this type of investigation and have not been shown to be unreasonable. Whereas a flame may not occupy the entire space, for a fire in the fully-developed or primary burning stage, the flames will occupy a large percentage of the total volume. This assumption will yield somewhat higher temperatures than may actually result, thus incorporating a factor of safety into this approach.

The temperature of the space is determined graphically from a plot of the temperature versus the theoretical fire duration. Curves are plotted on this graph for particular opening factors, as defined in equation, [11] below:

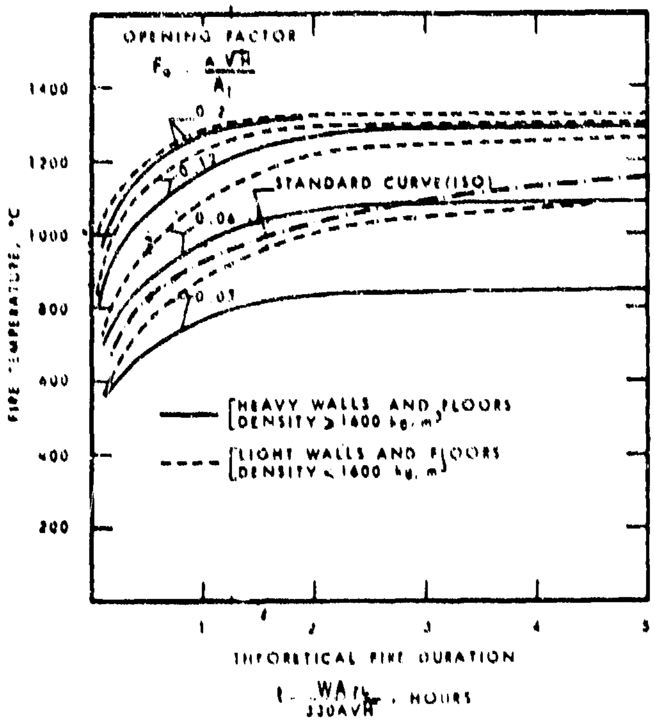
$$F_o = \frac{A_w\sqrt{h_w}}{A_T} \qquad [11]$$

Two curves are plotted for each opening factor, accounting for the effect of wall materials of the enclosure conducting heat away from the fire compartment. The fire duration is calculated by the following relation:

$$t = .026\,\frac{WA_{Fl}}{A_w\sqrt{h_w}} \qquad [12]$$

The temperature is determined by calculating the theoretical fire duration in equation [12] and the opening factor in equation [11] for the compartment. The time coordinate is located on the appropriate opening factor curve in Figure 2.1. The temperature coordinate of that point is the temperature of the upper room air temperature.

Figure 2.1 Temperature of Ventilation Controlled Fires



A – Window area (m²)
H – Window height (m)
A_t – Area of walls and floors (m²)
A_{FL} – Floor area (m²)
W – Fire load density (kg/m²)

The hot upper room air must be cooled so that the entire compartment will cool, thereby reducing the heat transfer from the components of the compartment to any available fuel. A temperature of 400°F is subjectively selected as an appropriate temperature to which the air should be cooled. 400°F is selected on the basis of it approximating the ignition temperature of most cellulosics.

The rate of heat loss required to cool the upper room air temperature to 400°F in one minute is given by:

$$\dot{q}_a = m_a c_p \Delta T \qquad [13]$$

And the mass of the air is:

$$m_a = \rho(\tfrac{1}{2}V) \qquad [14]$$

T.T. Lie (20) and McCaffrey and Rockett (21) show the pressure gradient within a fire compartment to be less than 5.5 x 10^{-4} pounds per square inch and thus can be considered constant. Therefore, since pressure, temperature and volume are constants, the air density must also be a constant. Visich (16) determined that C_p is independent of temperature and thus is also a constant. Substituting for ρ and c_p in equation [13] and [14] and for m_a in equation [13],

$$q_a = (.01)\ V\Delta T$$

2.3. Fire Control

Water acts as an extinguishant for solid fuel fires through cooling the fuel below its ignition temperature, and excluding oxygen. The water cools by absorbing heat from the fire. The absorption of heat results in the heating and possible vaporization of the water. Vaporization of the water into steam acts to displace oxygen from the fire. Displacement of a sufficient amount of oxygen by steam can result in extinguishment, however little quantitative information is available on this process. Therefore, for the purposes of this study, water is used to control the fire only through cooling.

2.3.1. Theory of Water Application for Fire Control

Water is applied in the vicinity of a fire through a nozzle. Once emitted

from the nozzle, the water stream breaks into droplets. These droplets are each individually heated and vaporized by the heat in the compartment. This can be modelled by a heat transfer analysis of the moving water droplets.

Yuen and Chen (22, 23, 24) have expended a considerable amount of effort in this area, as did Beyler (25) and Kanury (26). The evaporation of the droplets into steam is a rather complex problem, as is evident in the previously mentioned references. The amount of evaporation is dependent on the drop size, velocity of the droplets and several heat transfer parameters, e.g. Nusselt, Reynolds, Prandtl and Spalding numbers.

Drop Size

The size of the water droplet is a key factor in determining the ability of the applied water to cool the upper room air temperature and penetrate to the burning fuel (25). Small droplets evaporate readily, but can be easily carried off by the fire plume (27). The larger droplets are capable of penetrating the plume and reaching the fuel surface. Upon reaching the fuel surface, the water can act to cool the fuel below its fire point or inhibit the pyrolysis process.

An optimum drop diameter for evaporation only was identified as 0.4 to 0.6 mm in a series of English tests performed by Rasbash, Rogowski and Skeet in 1951 (27). However, an optimum diameter for penetration of the plume has been determined as 4.0 to 6.0 mm by Yao and Kalekar (29). Results from a series of German tests (27) concluded that the optimum drop diameter was approximately 0.35 mm, in agreement with Rasbash, et.al. A series of tests were conducted by the National Board of Fire Underwriters (28) varying droplet sizes in water sprays to extinguish fires of variable fuels. An optimum drop diameter appeared to be .30 mm.

The approach considered in this report does not consider the effects of the

water reaching the fuel, as in other approaches (4). However, the water is considered to reach the proximity of the base of the flames so as to promptly absorb heat released from the burning fuel.

In reality, the water droplets produced by a hose stream are not uniform in size (29). Further, variation of nozzle pressure or nozzle type alters the distribution of droplet sizes. Typical droplet size distributions for commonly used fire service nozzles and operating pressures should be determined in future studies.

2.3.2. Previous Studies on Fire Control with Water

Previous studies on fire control using hand-held hose lines indicate that the tactics employed for the application of water is a key parameter (30, 31). An earlier study by Royer and Nelson (31) suggested application methods and techniques for improved efficiency of water usage.

Salzberg, Vodvarka and Maatman (30) performed a series of tests utilizing teams of firefighters with varying experience to extinguish compartment fires. The efficiency of application of water from hand-held hoselines was dependent on the training of the team. The range for the quantity of water applied varied as much as 210 percent for the trained versus untrained teams (30, p. 27).

Attempts have been made to evaluate the percentage of applied water on a building fire which has an effect on the fire (31). These studies determined that approximately 67 percent of the water has an effect on the fire.

Whereas drop size and velocity are important variables, the training level of the users of hand-held hoselines appears to be the controlling variable. Therefore, a detailed study of heat transfer to the water droplets is not felt to be advantageous, because of time limits on the study (the concept should be addressed in any future studies, if a truly theoretically based model of fire suppression is desired). For this study, only 67 percent of the water applied from hoselines is considered to reach the vicinity of the fire. This percentage

is suggested subjectively and also should be validated or refuted in future studies.

2.3.3. Heat Absorption by Water

The amount of heat required to raise the temperature of one pound of water from 60°F to 212°F is $H = mc_p\Delta T = 152$ Btu. [16]

Once the pound of water has been heated to 212°F, the latent heat of vaporization is the amount of heat required to allow the water to vaporize. The latent heat of vaporization is 970 Btu/lb. Thus, the amount of heat which can be absorbed by water at 60°F by a change in state is 1,122 Btu/lb or 9,363 Btu/gal. Assuming 67 percent of the water reaches the vicinity of the fire and 75 percent of that water evaporates, the net efficiency of application is 50 percent. (This percentage is suggested subjectively and should be validated or refuted in future studies.) Therefore, one gallon of water absorbs one half of 9,363 Btu or 4,680 Btu.

The rate of heat absorption is given by the following expression:

$$4{,}680\ G = \dot{H}_e \qquad [17]$$

2.4. Calculation of Fire Flow

The fire flow, G, is determined by considering the heat release rate by the fire, the amount of heat loss required to cool the room air to an acceptable temperature (e.g. 400°F) and the heat absorption by water. This is accomplished by utilizing equations [7], [9], [15], [17] and the following basic principle:

$$\dot{H}_e = \dot{q}_F + \dot{q}_a \qquad [18]$$

The heat release rate of the fire, $\dot{q}_F$, is determined by equation [6] for ventilation controlled fires and equation [9] for fuel controlled fires. The heat loss rate required to cool the upper room air temperature in one minute, $\dot{q}_a$, is given by equation [15]. If the fire is determined to be fuel controlled, $\dot{q}_a$ may be neglected since the air flow should be sufficient, such that $\dot{q}_a$ will be small compared to $\dot{q}_F$.

Thus using equation [18] for ventilation controlled fires:

$$4680\ G = 5550\ A_w \sqrt{h_w} + .01\ V(\Delta T)$$

$$G = 1.19\ A_w \sqrt{h_w} + (2 \times 10^{-6})\ V\Delta T \qquad [19]$$

For fuel controlled fires:

$$4680\ G = .076\ A_f\ \Delta H_c \qquad [20]$$

If the fuels are chiefly cellulosic equation [20] can be revised, by substituting for ΔH_c (8,000 Btu/lb) and solving for G:

$$G = .130\ A_f \qquad [21]$$

2.4.1. <u>Adjustment for Exposures</u>

Radiant heat from windows in the fire compartment incident on nearby combustibles may be sufficient to cause their ignition if the heat flux is at least of a certain minimum value. Separation of the exposed combustibles from the radiating windows by an adequate distance will decrease the incident radiative heat flux, thereby preventing the ignition of the exposed combustibles.

If combustibles are not adequately distant from the radiator, ignition can be prevented by the application of water to maintain these materials below their ignition temperature. This quantity of water should be added to that obtained in equation [18] so as to prevent the spread of fire to neighboring buildings or other objects and to control the fire in the original fire building.

The first step in an analysis of the water required to protect exposed materials is to determine if they are safely separated by distance from the radiator. Lie (20) and Williams-Leir (33) have investigated this topic, though require that the fire temperature within the fire compartment be known. This is readily computed by utilization of Figure 2.1 and equations [11] and [12]. However, this analysis is only appropriate for ventilation controlled fires and is not readily computed for fuel controlled fires. Because of this limitation, adjustment for exposures on a theoretical basis, is not investigated in this study but should be examined in future studies.

2.4.2. Adjustment for Installed Fire Protection Equipment

This approach for calculation of fire flow has not considered the effects of any installed fire protection system. Automatic suppression systems can detect fires while still in an early stage of development, and promptly apply water, requiring only a small amount for extinguishment. Also, automatic detection systems can detect fires while still in an early stage of development alerting fire suppression forces who may be able to apply water before the fire is fully-developed, thereby not requiring as much water as if the fire reached the fully-developed stage.

Consideration of fire protection systems for the purpose of reducing the fire flow requirement is not readily quantifiable through a theoretical basis. However, such consideration does appear justifiable and should be researched on an empirical basis in future studies.

2.5. Calculation Technique Summarized

This section presents the resulting approach for a theoretically based calculation technique for determining the required amount of water for fire protection. The technique is based on the application of water to absorb the heat release rate from the fire and to cool the upper room air temperature. The technique is presented in steps for simplicity.

1. Fire Area:

   Select the largest area of the building within a one hour fire-rated compartment Location of fire area:__________

2. Unprotected Openings:

   For the boundary enclosure of the selected area, note the dimensions of all unprotected openings, e.g. doors, windows, etc., in feet. Complete the table below by calculating the area for each opening, the $A\sqrt{h}$ factor and summing the $A\sqrt{h}$ factors.

	1	2	3	4	5	6	7	8	9	10	Total
width (ℓ)											X
height (h)											X
area (A)											X
$A\sqrt{h}$											

3. Ventilation Parameter, ϕ:

   Determine the ventilation parameter, ϕ, by multiplying the total of all the $A\sqrt{h}$ factors obtained in (step 2) by 27.5.

   ϕ=__________

4. Fuel Surface Area, A_f:

   Calculate the surface area of all combustibles in the fire area. Where possible, simplify the procedure by selecting "rectangular boxes" of combustibles and computing the area of the four sides and top. Use the table below for this process or any other appropriate method for calculating A_f the total of the areas for the sides and top is A_f.

Rectangular Boxes of Combustibles

	1	2	3	4	5	6	7	8	9	10	Total
length (ℓ)											X
width (b)											X
height (h)											X
area-long sides ($2\ell h$)											
area-short sides (2bh)											
area-top (ℓb)											

$A_f = 2\ell h + 2bh + \ell b =$ __________

5. Control Mechanism of Fire:

Determine if fire is fuel or ventilation controlled by dividing ϕ (step 3) by A_f (step 4). $\frac{\phi}{A_f}$ = ________

If $\frac{\phi}{A_f} \geq 3.22$ fire is fuel controlled; proceed to step 6.

If $\frac{\phi}{A_f} < 3.22$ fire is ventilation controlled; proceed directly to step 9.

6. Fuel Composition:

Determine if the combustible materials are mostly cellulosic and circle the appropriate answer. Yes No

If no, proceed to step 7

If yes, proceed directly to step 8 and assume $\gamma = 1.0$

7. Fuel Composition Factor, γ:

a. Determine the composition of the fuel in the fire area excluding cellulosics e.g. synthetics, flammable liquids, etc.
b. Note the percentage of the total amount of combustibles which each type of fuel comprises (by weight) in the top row of the table, below.
c. In the second row, note the heat of combustion, ΔH_c, for each type of fuel.

Combustible Materials

	1	2	3	4	5	6	7	8	9	10	Total
Fuel Type											X
% of total											100
Heat of Combustion, ΔH_c											X
(% of total)x(ΔH_c)											

d. Sum of the (% of total) x (ΔH_c) for combustibles: ________
e. Calculate the percentage of all combustible materials in the fire area which are cellulosic (by weight). % cellulosic = ________
f. Multiply the percentage of cellulosics (step 7e) by 8000. 8000 x % of cellulosic = ________
g. Add the quantity in (line 7d) to (line 7f) and divide by 8000 to obtain γ

$$\gamma = \frac{(\text{step 7d}) + (\text{step 7f})}{8000} = \_\_\_\_\_\_\_\_$$

8. Rate of Heat Release, Fuel Controlled Fires:

Determine the rate of heat release from fuel controlled fires by multiplying the fuel surface area, A_f (step 4), by 610 and the fuel composition factor, γ (step 7f or assume 1.0)

$q_F = 610 \times \gamma \times A_f$ = ________

Proceed to step 12

9. Rate of Heat Release, Ventilation Controlled Fires:

Determine the rate of heat release from ventilation controlled fires in the fully-developed stage. Multiply ϕ (step 3) by 202.

$q_F = 202\phi$ = ____________

10. Upper Room Air Temperature:

Determine the upper room air temperature in the fire area.

a. For the boundary enclosure of the fire area, determine the area of the enclosing walls. Area of walls = ____________
b. Find the area of the ceiling of the fire area
Area of ceiling = ____________
c. Sum the areas of the walls (step 10a) and ceiling (step 10b) to determine A_T, the total surface area of the fire area. A_T = (step 10a +10b) = ____________
d. Calculate the opening factor, F_o by dividing ϕ (step 3) by 27.5 x A_T (step 10c). $F_o = \dfrac{\phi}{27.5\ A_T}$ = ____________
d. Determine the fuel load, w, in the fire area. w= ____________
f. Determine the following factor: $\dfrac{.715\ A_f W}{\phi}$

see (step 3) for ϕ, (step 4) for A_f and (step 10e) for W. $\dfrac{.715\ A_f W}{\phi}$ = ____________

g. Using Figure 2.1, determine the temperature using (step 10f) for one coordinate and (step 10d) to select the proper curve. T= ____________
h. Calculate the volume of the fire area. V= ____________

11. Heat Stored by Upper Room Air:

Determine the amount of heat stored by the warm upper room air which must be released for cooling by:
a. Subtract 400°F from the upper room air temperature (step 10g) T - 400 = ____________
b. Calculate: one percent of the room volume (step 10h).
.01V = ____________
c. Determine the product of (step 11a) and (step 11b).
.01V(T-400) = ____________

12. Fire Flow:

Determine the fire flow by dividing the rate of heat release from the fire [(step 8) for fuel controlled fire, (step 9 plus step 11c for ventilation controlled fires)] q_F by 4680.

$G = \dfrac{\dot{q}_F}{4680}$ = ____________

2.6. Summary

The theoretically based method for calculating fire flow has been presented in this section. The method is generally applicable to a variety of buildings, though does appear to have the following limitations.

First, the method appears to be most appropriate for well-compartmented buildings. One of the assumptions of the method involved the flames filling the entire compartment. Thus, for large, uncompartmented buildings, the method only addresses the case where the entire building is fully involved in fire, which is a small percentage of the fires and may be considered as an acceptable loss, if infrequent, under the conditions of crisis relocation. Use of the method for large, uncompartmented buildings may be improper and should be examined in more detail in future studies.

Another limitation of the method involves use of the method for windowless compartments or buildings. The method relies on the calculation of the ventilation factor, ϕ. If the area of the openings is very small, the ventilation factor will also be very small, resulting in the assessment of the fire as ventilation controlled. In this case, the fire flow requirement will also be very low because of the lack of openings. However, fires within this compartment may be quite intense before flashover.

The method addresses only the cases of post-flashover fires. As just noted, pre-flashover fires should also be analyzed relative to fire flow requirements. Further problems involving pre-flashover fires includes the possibility of the steam generation rate (and thus the efficiency of water application) being substantially lower, thereby requiring a higher rate of water be applied for control.

These limitations should be comprehensively investigated before use of this method can be recommended. Further, the assumptions need to be validated

(especially those made subjectively) and the results checked with actual required water application rates for control at real fire incidents before the method is extensively applied. Otherwise, this theoretically based technique appears to be appropriate for use at least as a foundation upon which a sophisticated and objective fire flow calculation method can be constructed.

Nomenclature

Symbols

A	-	Area (ft^2)
c	-	Specific heat (Btu/lb - ^oF)
F	-	Opening Factor ($ft.^{\frac{1}{2}}$)
g^o	-	Gravitational constant (32 ft/sec^2)
G	-	Water flow rate (gal/min.)
h	-	Height (ft.)
H	-	Enthalpy (Btu)
ΔH_c	-	Heat of combustion (Btu/lb)
ℓ	-	Length (ft.)
M	-	Mass (lb)
$\dot{m}$	-	Rate of mass loss (lb/min.)
$\dot{q}$	-	Heat release rate (Btu/min.)
$\dot{Q}$	-	Heat loss rate (Btu/min.)
r	-	Stoichiometric ratio
R	-	Rate of burning (lb/min.)
t	-	Time (min.)
T	-	Temperature, (^oF or ^oR)
V	-	Volume (ft^3)
W	-	Fuel load (p.s.f.)
Υ	-	Fuel composition factor
η	-	Efficiency of burning factor
ρ	-	Density (lb/$ft.^3$)
ϕ	-	Ventilation Parameter

Subscripts

a	-	Air
f	-	Fuel
F	-	Fire
Fl	-	Floor
i	-	Incident
I	-	Interior Surfaces
L	-	Convective loss
R	-	Radiation loss
T	-	Total surface area
w	-	Window

III. Review and Evaluation of the Existing Techniques for Calculating Fire Flow

Presently, several techniques are utilized for calculating the required fire flow for a particular building. These methods are reviewed and evaluated in this section, according to the criteria of internal validity, external validity and utility. A graphical comparison of the methods is also presented. From the review and comparison of the methods, the four most appropriate methods are selected for further use.

3.1. The Selected Techniques for Review and Evaluation

Twelve methods are selected for review and evaluation in this section. These twelve techniques represent a combination of well-known techniques from the past, currently widely-used techniques and recently developed techniques, but do not purport to be all-inclusive of the existing techniques.

In Table 3.1, the selected techniques are noted according to an author's or originating organization name. The variety of basic methodologies of the selected techniques by which the fire flow is calculated is also illustrated in Table 3.1. Some of the methods use only one equation, whereas others are comprised of a series of equations which must be simultaneously solved. Some techniques do not include any equations, using only a set of tables to compute the required fire flow.

The methodology of several techniques consists of a general type of table, graph or equation. Selection of the appropriate table, graph or specific equation often depends on particular features of the building, e.g. construction type of the building, height of the building, etc. Several of the techniques also allow for adjustment to results obtained from tables, graphs or equations because of special conditions, e.g. existance of an automatic fire suppression system, occupancy hazard, etc. The particular features or special conditions of the building included in the methodologies of the techniques are noted in Table 3.2.

TABLE 3.1 The Selected Techniques for Calculating Fire Flow

	graphs / tables	series of equations	one equation	basic* equation GPM =
Ball and Pietrzak (4)		●		
Bengston (37)			●	$C\ A^{0.664}$
Corlett & Williams (38)		●		
FIA (39)	●			
Hutson (40)			●	$1000 + \frac{A}{10}$
ICBO (41)			●	$\frac{A}{C}$
IITRI (30)			●	$- C_1\ A^2 + C_2\ A$
ISU (31)				$\frac{AH}{100}$ **
ISO (3)				$18C\ \sqrt{A}$
Milke (42)				$.2\ \sqrt{h}\ A$ ***
PFRB (43)	●			
Thomas (44)			●	$4.8\ \sqrt{A}$

*Basic equation is noted only if "one equation" is checked. C's noted in equations are constants, evaluated for specific conditions.

**H is height of building.

***h is height of window; (area of window is assumed as four per cent of floor area).

Key:

● Method utilizes the noted technique.

TABLE 3.2 Adjustments to Basic Methodologies

Methods	Building Height	Occupancy Hazard	Exposure Hazard	Fixed Protection	Construction Type	Other
Bali and Pietrzak						
Bengston		●				
Corlett & Williams						
FIA		●				
Hutson	●	●	●	●	●	●
ICBO		●	●			
IITRI		●				
ISU	●					
ISO		●	●	●	●	
Milke			●			
PFRB	●	●			●	
Thomas						
Theoretical			●			

Key:

● Method includes the noted adjustment.

3.2. Criteria for Evaluation

The criteria by which the various methods of calculating fire flow have been evaluated follow the general approach of the fire protection policy research reviews at the Georgia Institute of Technology and the New York City RAND Institute, supported by the National Science Foundation(34,35). These criteria were also used to evaluate systematic methods for grading fire safety at the University of Maryland (36). This approach involves the assessment of each technique with respect to the issues of internal validity, external validity and utility.

3.2.1. Internal Validity

The internal validity relates to the research conducted to formulate the method. Assessment of internal validity includes an investigation into the founding research for internal procedural errors, such as inadequate data, improper assumptions, etc. Basically the assessment of internal validity includes these concepts:

1) Is a valid data source specificied and does it appear to be properly utilized?

2) Are any assumptions noted and are they justified for the study? Are the assumptions proper for the analyses utilized in the research?

3) Are the analytical procedures correctly and properly used, e.g. statistical, experimental and theoretical analyses?

4) Are the conclusions logically developed from the data, assumptions and analyses?

Documentation of the founding research for many of the fire flow techniques is insufficient, requiring that some implicit data sources, assumptions, etc. be hypothesized. The items resulting from the necessary hypotheses were then evaluated.

3.2.2. External Validity

The external validity relates to the applicability and validity of the method to actual conditions. Three questions comprise the analysis for external validity.

1) Does the method yield results of a similar order of magnitude as other existing and widely accepted methods? This question attempts to address the concept of whether the method yields a result in agreement with the state-of-the-art. It should be noted that the state-of-the-art in this field is somewhat limited, e.g. it cannot be reliably predicted if a particular required fire flow will be successful in extinguishing a given building fire. Thus, this question is limited to a relative measure of "accuracy" (through a comparison with existing techniques) and cannot be an absolute measure.

2) Is the method self-contradictory?

3) What is the applicability of the method? Are there limitations on its application and if so are these explicity noted? The application of the method should require little judgment so that its precision is not compromised if several users apply it.

3.2.3. Utility

The criterion of utility relates to the practicality of the method. There are two main issues addressed by this criterion.

1) Are all input data items for utilisation of the method readily available? Are those items which are available also reliable, i.e. will they yield accurate results or are they, because of the sensitivity of the method, likely to introduce a large degree of error?

2) Is the user of the method required to have a high level of analytical skills as a prerequisite for utilization of the technique?

3.3. Evaluation of the Methods

Each method was analysed according to the criteria of internal validity, external validity and utility. The specific reviews for each method are included in the appendix. A tabular summary of the reviews is presented in Table 3.3.

Examination of Table 3.3 indicates that the two techniques developed by IITRI (30) and ISO (3) appear to fulfill all of the criteria, i.e. these two methods are the only ones which fare favorably in all columns of the table. The remaining ten methods do not adequately satisfy at least one question. A summary of Table 3.3 is presented in Table 3.4. A "no" appears in Table 3.4 if any of the columns for the particular criterion contain a "no". A "?" appears if a "?" appears in any column, without a "no" entry in another column of that same criterion.

TABLE 3.3 Evaluation of the Fire Flow Techniques

Fire Flow Techniques	Internal Validity				External Validity			Utility	
	Specified Data Source	Valid Assumptions	Correct Procedures	Appropriate Conclusions	Magnitude of Results	Avoid Self-Contradiction	Generally Applicable	Reliable Input Available	Implementation Skills
Ball & Pietrzak							?		No
Bengston			?		?		No		
Corlett & Williams							No	No	No
FIA		?	?	?			No		
Hutson		?	?	?				No	
ICBO	No	?	?			No			
IITRI									
ISO									
ISU							?		
Milke			No				?		
PFRB	?	?	?	?					
Thomas					?		No		

Blank - Correct Statement
? - Statement could not be determined to be definitely correct or incorrect
No - Incorrect Statement

TABLE 3.4 Comparison of the Methods According to the Review Criteria

	Internal Validity	External Validity	Utility
Ball & Pietrzak		?	No
Bengston	?	No	
Corlett & Williams		No	No
FIA	?	No	
Hutson	No		No
ICBO	No	No	
IITRI			
ISO			
ISU		?	
Milke	No	?	
PFRB	?		
Thomas		No	

Key
No: The criterion is not fulfilled.
? : The criterion can not definitely be evaluated as being fulfilled or unfulfilled.
Blank: The criterion is fulfilled.

Analysis of Table 3.4 results in the conclusion that four of the twelve methods do not have at least one "no". These four methods are the IITRI (30), ISO (3), ISU (31) and PFRB (43) methods and thus are the most favorably evaluated.

3.4 Comparison of the Methods

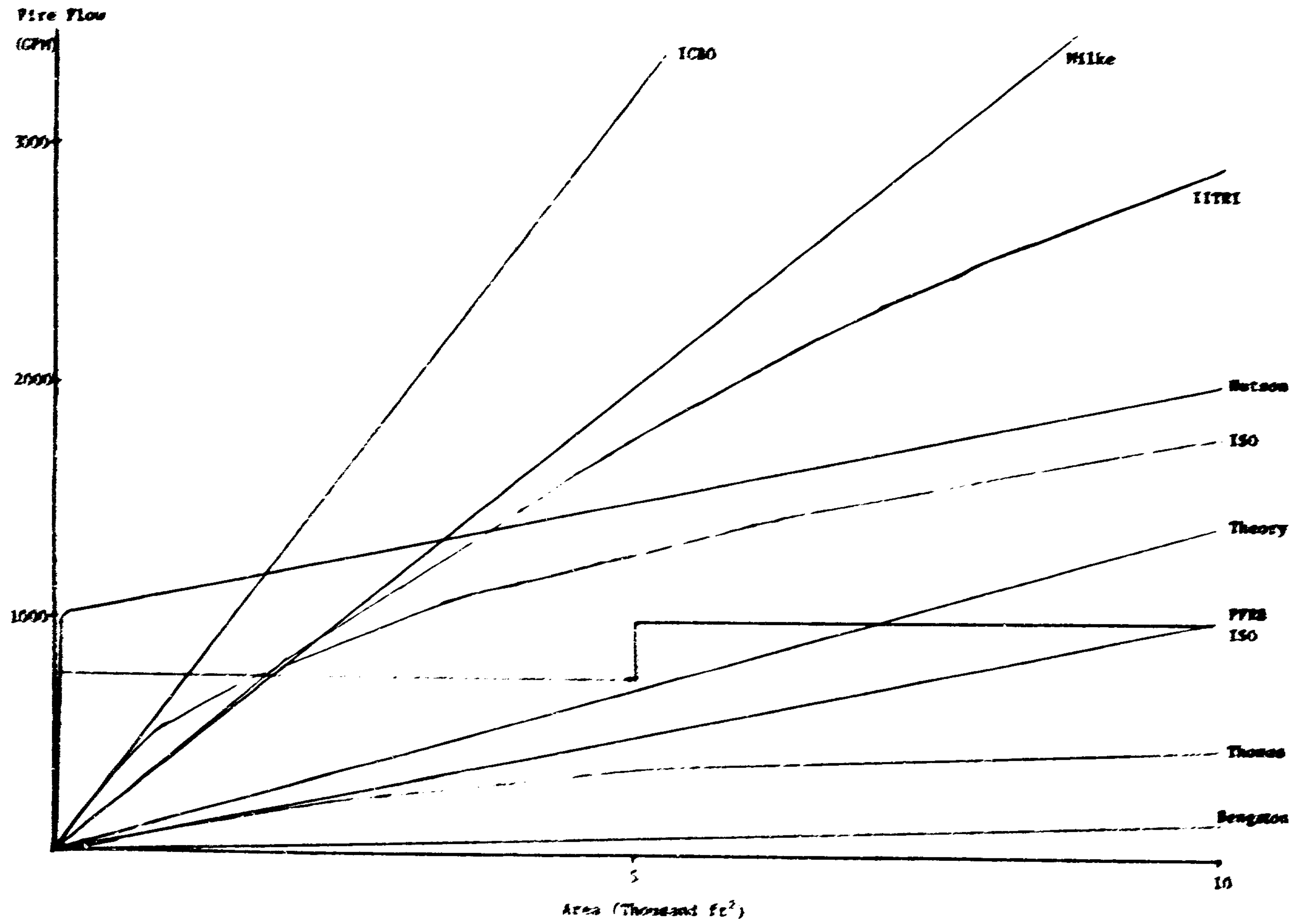
A comparison of the methods is useful to investigate which of the methods are most stringent (require the highest flows) or those which are least stringent (require the lowest flows). Several of the methods utilize the size of the fire area in the equation, thus a plot of the fire flow versus the fire area is used for this comparison. Since some of the methods consider construction type, occupancy hazard and other features as adjustments to the basic equation as previously noted, a one-story, ordinary construction type building with a moderate commercial occupancy hazard and no sprinklers or exposure hazard is considered for this comparison.

The plot of the fire flow versus fire area is presented in Figure 3.1. The techniques without a single basic equation, such as those by Ball and Pietrzak (4), and Corlett and Williams (38) are not amenable to a plot of this type with the information provided and thus are not included. Those methods utilizing tables did have sufficient information for the graph and thus are plotted in the figure.

The wide range of requirements as illustrated in Figure 3.1 may be attributed to the differing philosophies for requiring fire flow. Historically, fire flow requirements were formulated to prevent conflagrations. The ISO (3), ICBO (41), Hutson (40) and PFRB (43) techniques were formulated for this objective. Many techniques have resulted from a need to provide adequate water for extinguishment of fire only in a particular fire area. The empirically developed methods and theoretically based methods were formulated within this framework, e.g. IITRI (30), Thomas (44), Bengston (37), etc.

Some differences may be a result of the maximum fire area considered. Some of the methods require the area of the entire building to be utilized in determing

Figure 3.1 Required Fire Flow vs. Fire Area of Building



fire flow (PFRB, Hutson, ICBO, etc.) whereas other utilize only the maximum fire area (ISO, IITRI, Milke (42), etc.). If the building is not compartmented, the building area and maximum fire area are identical, however, in compartmented buildings the maximum fire area may be substantially less than the total building area.

3.5. Selection of the Four Most Appropriate Methods

Four methods, IITRI, ISO, ISU and PFRB, were the most favorably evaluated according to the criteria of internal validity, external validity and utility. For a fire area of 10,000 square feet, these four yield fire flow requirements which are third, fifth, seventh and eighth highest of the eleven graphed. Thus, these four appear to be a representative sampling of the range of required fire flows without being at either the highest or lowest extreme. Thus, these four are selected for use in subsequent analyses in this report.

IV. WATER DEMAND FOR CRISIS RELOCATION

There is a renewed focus on water supply requirements for major emergency situations. Under crisis conditions, it may be necessary to evacuate a given geographical region and relocate a large number of persons to communities some distance from the emergency site. The influx of a large number of persons to a specific community will impact on the local water and sewer system. This study phase considers the possible impact and the possible alternative water supply and demand arrangements to fulfill domestic consumption needs and fire suppression water needs during a crisis relocation condition. The case study presented has important implications for developing policy criteria for crisis relocations.

4.1 Introduction

The Village of Warsaw, New York is selected for the crisis relocation water supply and sewer system evaluation. This Village is currently participating in the development of a county wide Fire Prevention and Control Master Plan. Planning for crisis relocations could be an important part of this plan. In fact, the Wyoming County Fire Coordinator and Civil Defense Director plans to extend this study phase to the other villages and rural sectors of the county.

The prime objective of this study phase is to evaluate the increased water demand on the Warsaw water system under defined levels of population influx. This evaluation is correlated to the simultaneous potential demand for fire protection water during a crisis relocation period. A secondary study objective is to assess the impact of the water use demand on the Warsaw sewer system capacity.

4.2 Evaluation of the Water and Sewer System

The crisis relocation evaluation of the Warsaw water and sewer system considers the current capacity of each component of the system. This evaluation considers the supply characteristics of the water system, the ISO recommended fire

flow demand (3), the consumer consumption demand, and the potential crisis relocation demand by population groupings. Consumer consumption is further evaluated between commercial property, institutional property, local government property, and residential property. This assessment permits a further evaluation of alternative demand requirements.

Table 4.1 lists some general statistics of the Warsaw Water System. Included in the table are the water demand for domestic and fire protection needs, capability of the system to deliver a particular fire flow at a selected location and capacity of the system.

Table 4.1: Water and Sewer System Supply and Demand

Demand - Domestic	
Average Daily Consumption	680,000 gpd
Maximum Daily Consumption	994,444 gpd
Demand - Fire Protection*	
Maximum Required Fire Flow	5,000 gpm
Basic Fire Flow	3,500 gpm
Maximum Fire Flow Capability**	
2000 gpm for 1 hour	
1400 gpm for 6 hours	
694 gpm for 24 hours	
System Capacities	
Reservoir Storage	8,000,000 gallons
Sewer Treatment	1,200,000 gpd

*Demand requirements are determined utilizing the criteria developed by ISO (3), discussed in section 3.

**Measured at North Main and Buffalo Streets.

Table 4.2 lists the 147 non-residential properties served by the Warsaw water system according to 21 occupancy or use categories. The demands presented are for a 24 hour period.

Table 4.2: Domestic Water Demand by Occupancy

No. of Occupancies	Occupancy Category	Gallons/24 hrs.	
5	Churches	3,675	
3	Civic Clubs	2,600	
2	Public Schools	126,500	
1	Hospital	72,000	
2	Nursing Homes	27,000	
5	Barber Shops	1,100	
3	Beauty Shops	625	
6	Dental Offices	4,500	
16	Department Stores	6,390	
3	Drug Stores	1,080	
9	Industrial Plants	5,760	
1	Laundry	2,000	
2	Launderette - Cleaners	3,000	
4	Meat and Grocery Stores	3,200	
1	Motel - Hotel	1,250	
2	Physicians	400	
13	Restaurants	11,000	
17	Service Stations and Garages	10,800	
1	Theatre	900	
7	Local Government Bldg.	9,475	
44	Other Establishments	14,095	
Total Non-Residential			307,350
Single and Multiple Family Dwellings			546,469
Total Domestic Requirement			853,819

4.3 Water Demand During Crisis Relocation

The crisis relocation evaluation assumes that the normal activities of the building used for housing and feeding relocated persons will cease during the crisis relocation. Therefore, the normal daily consumption calculated for each facility can be reallocated to serve a stated influx of persons. This same concept can be applied to the community at large. The following analysis for the Village of Warsaw based upon these ideas.

Several properties have been identified by the current Director of Civil Defense, Wyoming County, N.Y., as possible sites for housing and feeding a relatively large number of persons under crisis relocation conditions. These

facilities are evaluated in terms of demand and supply "impact" on the Warsaw municipal water supply and sewer system. This information is shown in two separate sets of data in Table 4.3.

Table 4.3:[1] Relocation Sites

Set	Site Location	Sleeping/Feeding Capacity (persons)	Facility Requirement (gal)	Cumulative Demand (gal)
1	Warsaw High School	500	75,500	75,500
	Presbyterian Church	150	22,650	98,150
	Congregational Church	150	22,650	120,800
	I.O.O.F. Headquarters	75	11,325	132,125
	Methodist Church	75	11,325	143,450
	SUMMATION SET #1	950		143,450
2	Fire Stations #1 & #2	350	52,850	196,300
	Baptist Church	75	11,325	207,625
	Trinity Episcopal Church	100	15,100	222,725
	Knitting Mill	300	45,300	268,025
	SUMMATION SET #1 & #2	1,775		268,025

Table 4.3 indicates 950 persons could be located in facilities identified as Set #1 assuming normal daily consumption for the stated buildings. However, the normal use of these buildings would be curtailed so the water consumption can be reallocated to "crisis use." Thus, the water demand for the buildings comprising Set #1 would be only 130,175 gallons per day. This quantity of water can be considered in estimating the water available for the "crisis" relocation of persons to Warsaw, New York. Table 4.3 presents site locations in two sets for a specific reason. Water for fire suppression operations must be assessed simultaneously

[1]Note: Calculations are based upon Institutional, Commercial, and Industrial Water Consumption Requirements developed by the American Society of Civil Engineers (45).

with consumer consumption. Table 4.4 presents data concerning fire flow availability in terms of a gallon per minute delivery rate considering average daily consumption, maximum daily consumption, and the alternative consumption requirements under the two depicted crises relocation supplemental persons plans.

This type of analysis appears important in planning for crisis relocation movements and for determining threshold levels of relocated persons that can be accommodated by a given community <u>or</u> the alternative considerations that must be addressed <u>if</u> a larger number of persons are to be accommodated. One such alternative might be the shuttling of water from other treated water facilities. A second alternative might be the use of auxiliary water supplies for fire protection (i.e. tank trucks, dammed creeks, portable holding tanks strategically placed, reinforced ground level fabric tanks, etc.).

Table 4.4: <u>Relationship of Consumer Consumption Alternatives and Fire Flow Availability</u>

Domestic Consumption Condition	Fire Flow Available
Average Daily Consumption Rate (680,000 gal./day)	1920 g.p.m.
Maximum Daily Consumption Rate	1380 g.p.m.
Crisis Relocation Set #1 Plus ADC - Day Rate	480 g.p.m.
Crisis Relocation Set #1 & #2 Plus ADC - Day Rate	78 g.p.m.
*Instantaneous Flow Demand under ADC	720 g.p.m.
*Instantaneous Flow Demand under MDC	510 g.p.m.

*Note: Instantaneous flow demand considers peak periods on the water system for time periods not to exceed 20 minutes. (i.e. Evening meal time.)

The above analysis only considers the demand delivery rate on the water system under various consumption conditions. Duration of delivery rates has to be an important consideration in evaluating a water system under "Normal" operating conditions and under conditions of "crisis relocation". Table 4.5 depicts the duration of water delivery under four assumed demand conditions.

Table 4.5: Potential Duration of Delivery

Demand Condition	Duration Capability
Average Daily Consumption Rate	12 hours
Average Daily Consumption plus 1920 gpm for fire flow	8 hours
Average Daily Consumption plus Crisis Relocation Set #1 (No fire flow consideration)	9 hours
Average Daily Consumption plus Crisis Relocation Sets #1 + #2	8 hours

4.4 Preliminary Summary

The Village of Warsaw, New York water system has been evaluated relative to normal domestic consumption needs and special demand requirements. The special demand requirements consider water for fire protection purposes and alternative demands for defined sets of population movement in to the village under conditions of a "crisis relocation." This analysis leads to several important conclusions.

1. The maximum delivery rate of the water system does not meet the combined requirement for domestic consumption and fire flow simultaneously. Under conditions of maximum daily consumption the water system is 58% deficient.
2. The maximum delivery rate of the water provides average daily consumption plus fire flow under a condition of 49% deficiency.
3. The additional consideration of relocating persons in the Village of Warsaw under "crisis conditions" results in a consumer

consumption demand that leaves practically no water available for fire protection purposes. Therefore, auxiliary supplies must be considered for fire protection purposes.

4. A potentially attractive way of handling water demand in the host city is to provide an adaptive scheduling of instantaneous flow demand for each of the location sites where people are fed and housed. Adaptative scheduling could avoid the situation of simultaneous demand from several community relocation centers. Pro-rated adaptive scheduling could permit a water system, such as the Warsaw example, to accommodate a larger number of individuals than could be permitted under per capita analysis using the ASCE criteria for instantaneous flow demand.

4.5 Sewer Treatment Requirements

Municipal water and sewer systems have an interesting design relationship. A high percentage of the water used for consumer consumption finds its way into the sanitary sewer system. The American Water Works Association recommends that sewer capacity be designed to accommodate from 80 per cent to 100 per cent of the maximum day ra.e of a given water supply system (45). The peak capacity of the sewer system may consider the overload capacity of the treatment process for a maximum of three hours.

The specific consideration of sewage treatment for Crisis Relocation Planning (CRP) has been investigated by Fisher, Dickenson, Meyer and Wagner (46). Their final report titled Emergency Sewage Procedures During Crisis Relocation provides a sound technical document on sewer treatment considerations for the host community. Part II of that study

provides an operational manual organised around the different classification of treatment processes. Following a brief description of each process are corresponding worksheets detailing each individual calculation needed to estimate performance of the different processes and identifying potential trouble areas within the plant. The worksheets provide a step-by-step analysis of present operating conditions, the projected operational loadings during Crisis Relocation, and the effect of these increased loadings on process operations. Part III of that report deals with the disposal of waste water in non-sewered areas.

This study phase is directly concerned with the assessment of water and sewer supply and demand characteristics for the Village of Warsaw, New York. Consideration has already been given to water demand during a potential crisis relocation to this Village (Section 4.3). This section considers the characteristics and capabilities of the Warsaw sewer system under the condition of a crisis relocation.

Warsaw employs a primary sedimentation sewer system. The treatment process consists of holding the waste water in a large tank under quiescent conditions to remove suspended solids by settling under the influence of gravity. A primary clarifier provides a method of removing approximately one-third of the Biochemical Oxygen Demand (BOD), and about two-thirds of the suspended solids from the domestic waste water. The amount of BOD and suspended solids removed in the primary clarifier has a direct effect on the peak load which must be handled by other treatment processes (i.e. chlorination); for this reason it is important to evaluate the treatment overload efficiency of the primary clarifier and crisis relocation conditions.

The hydraulic overflow rate is the major parameter that governs the

efficiency of the primary clarifier for removing both suspended solids and BOD. Therefore, this "rate" is evaluated and charted in Table 4-6 for the Warsaw sewer system. It should be noted that the Warsaw treatment facility was modified and expanded in 1979. Not only has the treatment process been expanded to a day rate of 1,200,000 raw gallons but the primary trunk lines from the center portion of the community have been replaced with higher capacity conduit. Therefore, it should be observed that currently the sewer system capacity exceeds the maximum water consumption rate by approximately 200,000 gallons of waste water per day.

The data summary presented in Table 4-3 provides some important insights concerning the current capability of the Warsaw treatment plant to handle the potential influx of persons due to a crisis relocation condition.

Table 4-6 Sewer System Treatment Rate Characteristics

System Design Rate Capacities.	1,200,000 gpm 834 gpm
*Water Supply - Sewer System Balance Rate.	926 gpm
Sewer System Hydraulic Overload (3 hr. period)	1,268 gpm
Sewer System Hydraulic Overload with Supplemental Chlorination (3 hr. period)	1,535 gpm

*Note: Based upon published water consumption rates and corresponding treatment requirements it may be assumed that 20 per cent of the water used does not enter the sewer system.

This evaluation clearly illustrates that for demand periods up to 3 hours, the Warsaw sewer system can handle more waste water than the water system can deliver for domestic consumption.

4.6 Supplemental Waste Facility Capability

Current Crisis Relocation (CR) plans require that a large proportion of the host area population be located in rural areas which are generally not served by public sewage systems. Warsaw is a moderately sized village in the heart of a rural dairy county. Previous studies indicate that 15% of the Village fringe area uses septic tanks(47). The entire area outside the Village is serviced by individual septic services.

This study is limited to the potential impact of a crisis relocation of people to the Village of Warsaw, New York. The service capability beyond the village limits is beyond the scope of this study. However, a variable alternative to locating large numbers of persons in communities, municipalities, and villages is to disperse the relocated persons to individual private residences in rural areas.

V. Model Building Code and Water Supply Requirements

Water supply requirements for domestic and fire protection needs in the event of crisis relocation were discussed in the preceding sections. The theoretically-based method and the four most appropriate methods for calculating fire flow previously discussed along with the calculation method for domestic needs will now be applied to investigate the impact of model building code requirements upon water supply requirements. The four model building codes regulate the maximum height and area of buildings by the construction type and occupancy class of the building, all of which are factors considered in calculating water supply requirements. Thus, it appears that these building code requirements may affect water supply requirements.

5.1 The Selected Buildings and Complexes for Analysis

Ten individual building types and six types of complexes of buildings are selected for analysis of the apparent relationship between building code and fire flow requirements. The selected buildings and complexes consist of a variety of buildings without intending to be all-inclusive of the many types of buildings and complexes of buildings. Those types selected are considered to be appropriate examples of a wide variety of buildings and thus building code and water supply requirements. These buildings also are selected considering the condition of crisis relocation on a community, to which it may be desirable to maintain the delivery of an adequate supply of water for domestic and fire protection requirements.

The sixteen selected buildings and complexes are noted in Table 5.1 with a brief description of each. The first ten refer to individual buildings, whereas the remaining six complexes refer to a cluster of buildings.

5.2 Model Building Codes Selected for Analysis

The four model building codes widely utilized in the United States are:

Table 5.1 The Selected Building and Complex Types

Hospital: Building contains occupants with limited mobility due to being under medical care (48).

High-Rise Office: Building of at least six stories in height which is occupied for business purposes (48).

Furniture Warehouse: Building containing furniture for retail and storage purposes.

Mattress Factory: Building in which mattresses are manufactured and raw materials and finished products are stored.

Department Store: Building containing merchandise of a wide variety of materials, generally not highly combustible for display and sale (48).

Library: Building containing large quantities of books and other assorted reading material and space for more than 50 or more persons to congregate for use of these materials (48).

Detached Single Family Dwelling: Building in which persons of one family reside and sleep which is separated by distance from neighboring buildings (48).

Attached Single Family Dwelling: Building in which persons of one family reside and sleep which is separated from neighboring buildings by one-hour, fire-rated partitions (48).

Garden Apartment: Building of three stories in height or less in which persons of more than one family reside and sleep (48).

Rolled Paper Warehouse: Building contains rolled paper materials chiefly for storage purposes (48).

High Density Residential Complex: More than one building of the garden apartment type or one residential unit per 5,000 square feet or less (49).

Medium Density Residential Complex: More than one detached single family dwelling with a density between one residential unit in 5,000 square feet and one in 20,000 square feet (49).

Low Density Residential Complex: More than one detached single family dwelling with a density of more than one residential unit in 20,000 square feet (49).

Detached Commercial Complex: Several buildings containing products for display and sale, with buildings being in close proximity to each other (e.g. 30 feet separation between buildings) (48).

Shopping Center: Several commercial buildings (used for the display and sale of assorted merchandise) housed under a single roof.

Industrial Park: Several buildings used for the manufacture and/or storage of materials of limited combustibility, for which the manufacturing process is not highly hazardous.

BOCA Basic Building Code by the Building Officials and Code Administrators International, Inc. (BOCA) (50)

National Building Code by the American Insurance Association (AIA) (51)

Standard Building Code by the Southern Building Code Congress International, Inc. (SBCC) (52)

Uniform Building Code by the International Conference of Building Officials (ICBO) (53)

5.2.1 Occupancy Classes

The model building codes classify buildings according to occupancy. Each code has a unique set of occupancy classes. Conceptually, the classes are similar for the codes, however many of the specific classes are not identical, even if the same letter is used for a particular occupancy class.

The occupancy classes for the sixteen selected buildings and complexes according to the four model building codes is presented in Table 5.2. Examination of the table indicates that the sixteen buildings and complexes are classified by ten different occupancy classes by BOCA, eight by AIA and SBCC and six by ICBO.

5.2.2 Construction Types

The model building codes categorize the structure into construction types, based on composition and fire resistivity of the materials utilized for the structural members. Each model code has a unique stystem of classification, however the systems are not entirely dissimilar. A comparison of the classification systems is presented in Table 5.3

5.2.3 Maximum Height and Area Limits

The four model building codes limit the maximum height and area of buildings by occupancy class and type of construction. The BOCA, SBCC and ICBO codes specify these limits by a matrix of construction types and occupancy classes.

Table 5.2 Occupancy Types of the Selected Buildings and Complexes

	BOCA	AIA	SBCC	ICBO
Hospital	I-2	Health-Care	I	I Div. 1
High-Rise Office Building	B	Business	B	B Div. 2
Furniture Warehouse	S-1	Storage	S	B Div. 2
Mattress Factory	H	High Hazard	H	H Div. 3
Department Store	M	Mercantile	M	B Div. 2
Library	A-3	Educational	A-2	A Div. 3
Single Family Dwelling	R-4	Residential	R	R Div. 3
Townhouse	R-3	Residential	R	R Div. 3
Garden Apartment	R-2	Residential	R	R Div. 1
Rolled Paper Storage Warehouse	S-1	Storage	S	B Div. 2
High Density Residential Complex	R-3	Residential	R	R Div. 3
Moderate Density Residential Complex	R-4	Residential	R	R Div. 3
Low Density Residential Complex	R-4	Residential	R	R Div. 3
Detached Commercial Complex	M	Mercantile	M	B Div. 2
Shopping Center	M	Mercantile	M	B Div. 2
Industrial Complex	F	Industrial	F	B Div. 2

Table 5.3 Classification of Construction Types According to the Model Building Codes

CODE	TYPE OF CONSTRUCTION										
	FIRE RESISTIVE		NON PROT.		COMBUSTIBLE UNPROT.	HEAVY TIMBER	ORDINARY		WOOD FRAME	
							PROT.	UNPROT.	PROT.	UNPROT.
	A	B	A	B						
BOCA	IA	IB	IIA	IIB	IIC	IIIA	IIIB	IIIC	IVA	IVB
AIA	F.R.A.	F.R.B.	PROT. LTD. COMB.	-	UNPROT. LTD. COMB.	H.T.	ORD.	-	WOOD FRAME	-
SBCC	I	-	II	IV 1 Hr. PROT.	IV UNPROT.	III	V 1 Hr. PROT.	V UNPROT.	VI 1 Hr. PROT.	VI UNPROT.
ICBO	I	-	II FR	II 1 Hr.	IIN	IV	III 1 Hr	IIIN	V 1 Hr.	V N

The AIA code specifies these limits by construction type which is then altered by consideration of each occupancy class with the types of construction.

The maximum height and areas specified by each of the model codes are noted in Tables 5.4 through 5.7 for the occupancy classes of interest for this project, i.e. those classes which relate to the sixteen selected buildings and complexes.

5.3 Fire Flow Requirements

The four most appropriate existing methods for calculating fire flow were identified in an earlier section. A theoretically-based method was also described in an earlier section. The four existing methods and the theoretically-based method are applied in this section to calculate the water supply requirements for fire protection for the largest buildings of the sixteen selected types which are permitted according to the four noted model building codes.

5.3.1 Application of the Fire Flow Calculation Techniques

The four existing calculation techniques (discussed in section III) (30,3,31, 43) all utilize floor area of the building. However, the methods by ISO (3) and PRFB (43) consider the total floor area of the building within a two-hour fire resistant enclosure. The methods by IITRI (30) and ISU (31) utilize the floor area of the segment of the building involved by the fire. The theoretically-based method (developed in Section II) utilizes window and door area of the compartment involved by the fire. Some of these fire flow methods allow adjustments to be made or require that certain conditions, e.g. occupancy hazard, etc. be known before application of the technique is possible.

Therefore, in order that meaningful comparisons can be made between the results of the calculation techniques, certain assumptions are determined to be necessary. The assumptions are noted below individually for each technique.

Table 5.4 Height and Area Limits According to:

BOCA*

	Type of Construction									
	1A	1B	2A	2B	2C	3A	3B	3C	4A	4B
A-3	X	X	5st,65' 19,950	3st,40' 13,125	2st,30' 8,400	3st,40' 12,600	3st,40' 11,550	2st,30' 8,400	1st,20' 8,925	1st,30' 4,200
B	X	X	7st,85' 34,200	5st,65' 22,500	3st,40' 14,400	5st,65' 21,600	4st,50' 19,800	3st,40' 14,400	3st,40' 15,300	2st,30' 7,200
F	X	X	6st,75' 22,800	4st,50' 15,000	2st,30' 9,600	4st,50' 14,400	3st,40' 13,200	2st,30' 9,600	2st,30' 10,200	1st,20' 4,800
H	5st,65' 16,800	3st,40' 14,400	3st,40' 11,400	2st,30' 7,500	1st,20' 4,800	2st,30' 7,200	2st,30' 6,600	1st,20' 4,800	1st,20' 5,100	N.P.
I-2	X	8st,90' 21,600	4st,50' 17,100	2st,30' 11,250	1st,20' 7,200	2st,30' 10,800	2st,30' 9,900	1st,20' 7,200	1st,20' 7,650	N.P.
M	X	X	6st,75' 22,800	4st,50' 15,000	2st,30' 9,600	4st,50' 14,400	3st,40' 13,200	2st,30' 9,600	2st,30' 10,200	1st,20' 4,800
R-2	X	X	9st,100' 22,800	4st,50' 15,000	3st,40' 9,600	4st,50' 14,400	4st,50' 13,200	3st,40' 9,600	3st,40' 10,200	2½st,35' 4,800
R-3	X	X	4st,50' 22,800	4st,50' 15,000	3st,40' 9,600	4st,50' 14,400	4st,50' 13,200	3st,40' 9,600	3st,40' 10,200	2½st,35 4,800
S-1	X	X	5st,65' 19,950	4st,50' 13,125	2st,30' 9,600	4st,50' 12,600	3st,40' 11,550	2st,30' 8,400	2st,30' 8,925	1st,20' 4,200

*areas are 1 & 2 st. bldgs. only.

Key:
UH Unlimited Height
UA Unlimited Area
NP Not Permitted

Table 5.5 Height and Area Limits According to:

AIA

General Table

Construction Type	Height Limits (ft.)	Area Limits (ft^2) One Story	Multi-Story
Fire Resistive Type A	UH	UA	UA
Fire Resistive Type B	85	UA	UA
Protected Limited Combustible	75	18,000	12,000
Heavy Timber	65	12,000	8,000
Ordinary	45	9,000	6,000
Unprotected Limited Combustible	35	9,000	6,000
Wood Frame	35	6,000	4,000

Alterations to General Table

	Type of Construction						
Occupancy	Fire A	Resistive B	Protected Limited Combustible	Heavy Timber	Ordinary	Unprotected Limited Combustible	Wood Frame
Health-Care	-	-	1 st.	NP	NP	NP	NP
Hight Hazard	-	-	2 st.	NP	NP	1 st.	NP
Residential	-	-	-	-	3 st.	3 st.	2 st.
Storage	-	-	-	5000	5000	5000	5000

No changes to general table necessary for business, educational, industrial or mercantile occupancies.

Key:
UH Unlimited Height
UA Unlimited Area
NP Not Permitted

Table 5.6 Height and Area Limits According to:

SBCC

Occupancy	Type of Construction								
	I	II	III	IV Prot.	IV Unprot.	V Prot.	V Unprot.	VI Prot.	VI Unprot.
A-2	UH UA	80' UA	1 st 12,000	1 st 12,000	1 st 8,000	1 st 12,000	1 st 8,000	NP	NP
B	UH UA	80' UA	5 st 25,500	5 st 25,500	2 st 17,000	5 st 21,000	2 st 14,000	2 st 13,500	2 st 9,000
H	4 st 11,500	3 st 8,300	2 st 7,500	1 st 5,000	1 st 5,000	1 st 5,000	1 st 5,000	NP	NP
F	UH UA	80' UA	3 st 31,500	2 st 31,500	2 st 21,000	2 st 22,500	2 st 15,000	1 st 15,000	1 st 10,000
I	UH UA	80' UA	2 st 24,000	2 st 21,000	NP	2 st 21,000	NP	1 st 22,500	NP
M	UH 15,000	80' 15,000	5 st 13,500	5 st 13,500	2 st 9,000	5 st 13,500	2 st 9,000	2 st 9,000	2 st 6,000
R	4 st UA	4 st UA	3 st 18,000	4 st 18,000	3 st 12,000	4 st 18,000	3 st 12,000	3 st 10,500	2 st 7,000
S	UH UA	6 st 30,000	2 st 24,000	2 st 24,000	2 st 16,000	2 st 24,000	2 st 16,000	1 st 9,000	1 st 6,000

Key:
UH Unlimited Height
UA Unlimited Area
NP Not Permitted

Table 5.7 Height and Area Limits According to:

ICBO

Occupancy	TYPE OF CONSTRUCTION							
	I	II			III		IV	V	
		FR	1 hr.	N	1 hr.	N	H.T.	1 hr.	N
ADiv3	UH UA	12 st. 22,500	2 st. 10,100	1 st. 6,800	2 st. 10,100	1 st. 6,800	2 st. 10,100	2 st. 7,900	1 st. 4,500
BDiv2	UH UA	12 st. 30,000	4 st. 13,500	2 st. 9,000	4 st. 13,500	2 st. 9,000	4 st. 13,500	3 st. 10,500	2 st. 6,000
HDiv3	UH UA	5 st. 18,600	2 st. 8,400	1 st. 5,600	2 st. 8,400	1 st. 5,600	2 st. 8,400	2 st. 6,600	1 st. 3,800
IDiv1	UH UA	3 st. 11,300	1 st. 5,100	NP	1 st. 5,100	NP	1 st. 5,100	1 st. 3,900	NP
RDiv1	UH UA	12 st. 22,500	4 st. 10,100	2 st. 6,800	4 st. 10,100	2 st. 6,800	4 st. 10,100	3 st. 7,900	2 st. 4,500
RDiv3	UH UA	3 st. UA	3 st. UA	3 st. UA	3 st. UA	3 st. UA	3 st. UA	3 st. UA	3 st. UA

total area of all floors $\leq$ 2 x 1 st. area (shown above)

Key:
Height (stories)
Area (ft^2)

UH Unlimited Height
UA Unlimited Area
NP Not Permitted

IITRI (30)

1. The fire area included in the equation is the total floor area contained within one-hour, fire-rated, vertical and horizontal assemblies, e.g. floors and walls.

2. For residential occupancies, the fire flow is given by:

$$G = 0.5\,A - 9 \times 10^{-5}\,A^2$$

where the fire area, A, is:

$$200 < A < 5{,}000 \text{ ft}^2$$

3. For non-residential occupancies, the fire flow is given by:

$$G = 0.42\,A - 1.3 \times 10^{-5}\,A^2$$

where the fire area, A, is:

$$1{,}000 < A < 30{,}000 \text{ ft}^2$$

ISO (3)

1. The area A, is the floor area of the building.

2. The occupancy hazard is considered to be moderate except as noted blow:

   Low: Residential occupancies, high-rise office
   High: Mattress factory

3. Buildings are not considered to be sprinklered, unless entire building must be sprinklered according to the model building code for all buildings of that particular occupancy class.

4. No exposure hazard surcharges are included, except as noted below:

   a. High Density Residential: 25%
   b. Detached Commercial: 20%
   c. Medium Density Residential and Industrial Park: 15%

ISU (31)

1. The fire area considered in this technique is the total floor area contained within one-hour, fire-rated, vertical and horizontal assemblies, e.g. floors and walls.

2. The height of a story is twelve feet.

PFRB (43)

1. Combustible contents for all buildings are considered to be either 'C" (moderate burning rate) or 'D' (fairly rapid burning rate) except in mattress factory where combustible contents are assumed to be of degree 'E' (quite rapid burning rate) (43, p. 5).

Theory

1. Window area is assumed to be ten percent of the floor area of the compartment. This assumption results from model building code provisions for openings in exterior walls, unless the building is sprinklered, as shown below. The codes formulated by BOCA and ICBO require 20 square feet of openings for each 50 feet of perimeter (section 1202.13 of the 1978 edition of the BOCA Basic Building Code (50) and 3802.1 of the 1976 edition of the Uniform Building Code (53). If the building is assumed to have a square foundation, then the area of the building, A_b is:

   $$A_b = \tfrac{1}{4}\,(\text{Perimeter})^2$$

   Then the ratio of the area of the window, A_w can be related to the building area, in accordance with the requirements of the cited sections is:

   $$\frac{A_w}{A_b} = \frac{20}{\left(\frac{50}{4}\right)^2} = 12.8\%$$

   Therefore: $A_w = .128\ A_b$ which is rounded-off to yield: $A_w = .10\ A_b$, since the 1976 edition of the National Building Code (51) and Standard Building Code (52) produce ratios slightly lower than 0.1 when following the same procedure as presented above.

2. Window height is assumed to be 4 feet.

3. The average fuel height is assumed to be three feet for all occupancy classes, except residential, high-rise office and hospital where the fuel height is assumed to be one foot. Considering these fuel heights all fires are concluded to be fuel controlled as $\frac{\phi}{A_f}$ is always greater than 3.22 for floor areas in excess of 27.7 square feet.

5.3.2 Selection of the Largest Permitted Buildings.

Since the required fire flow is directly proportional to the total floor area of the building, then larger floor areas imply higher fire flows. As previously noted, the model building codes limit the height and area (and thus total floor area) of buildings, according to the construction type of the building.

Thus, to calculate the highest fire flow requirements associated with buildings in compliance with the model building codes, the largest permissible total floor area for the sixteen selected buildings and complexes must be determined for the various types of construction. This is determined through the application of

Tables 5.4, 5.5, 5.6 and 5.7 for the appropriate code along with the stipulated adjustments. Thus, the total maximum, permissible floor area is not simply the product of the maximum allowable floor area and the maximum allowable number of stories. BOCA and ICBO require adjustments to be made to the maximum allowable floor area for buildings greater than two stories in height. The other two model codes by SBCC and AIA require no adjustment, thus the maximum height and area of a given building is simply the maximum height and the maximum area of the building for a particular occupancy class. The buildings resulting in the largest allowable total floor areas for the codes formulated by BOCA and ICBO are noted in Tables 5.8 and 5.9 for SBCC in Table 5.6 and for AIA in Table 5.10.

5.3.3 Fire Flow Calculations

Fire flow requirements for the largest permissible building according to the four model building codes were computed utilizing the five calculation techniques. The results of these calculations are presented in Tables 5.11 through 5.14. Fire flows are noted in units of gallons per minute (gpm) for each recognized construction type by the respective code.

Examination of the four tables indicates that there are three designations other than quantities: "UL", "NP" and "*". The "UL" indicates the fire flow requirement is unlimited, a result of the code allowing the building area to be unlimited. "NP" is noted in cases where the code does not permit the occupancy for the particular construction types. "*" is indicated if the limitations of the fire flow calculation technique were exceeded.

5.4 Discussion

Fire flow requirements have been presented for a variety of occupancy of several construction types as regulated by the four major model building codes. A wide range of fire flow requirements are apparent in the Tables 5.11 through 5.14. In this section,

Table 5.8 Maximum Allowable Building Height and Area According to:

BOCA

	Type of Construction									
	I		II			III			IV	
Occupancy	A	B	A	B	C	A	B	C	A	B
A-3	UL	UL	5 st 16,960	3 st 10,500	2 st 8,400	3 st 10,080	3 st 9,240	2 st 8,400	8,925	4,200
B	UL	UL	7 st 25,650	NP	NP	NP	NP	NP	NP	NP
F,M	UL	UL	6 st 18,240	4 st 12,000	2 st 9,600	4 st 11,520	3 st 10,560	2 st 9,600	2 st 10,200	4,800
H	5 st 16,800	3 st 14,400	3 st 10,830	2 st 7,500	4,800	2 st 7,200	2 st 6,600	4,800	5,100	NP
I-2	UL	8 st 21,600	4 st 15,390	2 st 11,250	7,200	2 st 10,800	2 st 9,900	7,200	7,650	NP
R-2,3	UL	UL	4 st 20,520	4 st 12,000	3 st 7,680	4 st 11,520	4 st 10,560	3 st 7,680	3 st 8,160	2½ st 4,800
S-1	UL	UL	5 st 16,960	4 st 10,500	2 st 9,600	4 st 10,080	3 st 9,240	2 st 8,400	2 st 8,925	4,200

Table 5.9 Maximum Allowable Building Height and Area According to:

ICBO

	Type of Construction								
	I	II			III		IV	V	
Occupancy		FR	1 Hr.	N	1 Hr.	N		1 Hr.	N
ADiv3	UL	22500	10100	1 St. 6800	10100	1 St. 6800	10100	7900	1 St. 4500
BDiv2	UL	6 St. 10000	13500	9000	13500	9000	13500	10500	6000
HDiv3	UL	18600	8400	1 St. 5600	8400	1 St. 5600	8400	6600	1 St. 3800
IDiv1	UL	11300	1 St. 5100	NP	1 St. 5100	NP	1 St. 5100	1 St. 3900	NP
RDiv1	UL	22500	10100	6800	10100	6800	10100	7900	4500
RDiv3	UL	UL	UL	UL	UL	UL	UL	UL	UL

All buildings 2 story, unless otherwise noted.

Table 5.10 Maximum Allowable Building Height and Area According to:

AIA

Occupancy	FR A	FR B	PLC	HT	Ord.	ULC	WF
Business	UL	UL	6 St. 12,000	5 St. 8,000	4 St. 6,000	3 St. 6,000	3 St. 4,000
Educational Industrial Mercantile	UL	UL	6 St. 12,000	5 St. 8,000	4 St. 6,000	4 St. 6,000	3 St. 4,000
Health-Care	UL	UL	1 St. 18,000	NP	NP	NP	NP
High Hazard	UL	UL	2 St. 12,000	NP	NP	NP	NP
Residential	UL	UL	3 St. 12,000	3 St. 8,000	3 St. 6,000	3 St. 6,000	2 St. 4,000
Storage	UL	UL	6 St. 12,000	5 St. 8,000	4 St. 5,000	4 St. 5,000	3 St. 5,000

Table 5.11 Fire Flows for Maximum Height and Area Buildings Allowed by:

BOCA

Type of Construction

Occupancy	I A	I B	II A	II B	II C	III A	III B	III C	IV A	IV B
A-3										
IITRI	UL	UL	3380	2980	3380	2910	2770	3380	2710	1530
ISO	UL	UL	4250	2500	1750	3250	3000	2250	2500	1750
ISU	UL	UL	2040	1260	2020	1210	1110	2020	1070	500
PFRB	UL	UL	2000	1750	1250	1750	1250	1250	1000	750
Theory	UL	UL	2408	1520	2390	1470	1350	2390	1310	650
Hi-Rise B										
IITRI	UL	UL	2220	NP	NP	NP	NP	NP	NP	NP
ISO	UL	UL	4500	NP	NP	NP	NP	NP	NP	NP
ISU	UL	UL	3078	NP	NP	NP	NP	NP	NP	NP
PFRB	UL	UL	2250	NP	NP	NP	NP	NP	NP	NP
Theory	UL	UL	3420	NP	NP	NP	NP	NP	NP	NP
F,M										
IITRI	UL	UL	3360	3170	3270	3110	2990	3270	2930	1720
ISO	UL	UL	4750	3250	2000	4250	3750	3000	3750	2000
ISU	UL	UL	2190	1440	2300	1380	1270	2300	1220	580
PFRB	UL	UL	2000	1750	1250	1750	1750	1250	1570	750
Theory	UL	UL	2580	1730	2510	1670	1530	2510	1480	730
H										
IITRI	3390	3350	3020	2430	1720	2350	2210	1720	1800	NP
ISO	2000	1500	1500	1000	750	1500	1250	750	1250	NP
ISU	2020	1730	1300	900	580	860	790	580	610	NP
PFRB	2500	2000	2000	1500	750	1500	1500	750	1250	NP
Theory	2390	2060	1570	1110	730	1070	980	730	770	NP
I-2										
IITRI	UL	3010	1380	3080	4500	3020	2880	4500	2450	NP
ISO	UL	1500	1750	1250	750	1500	1250	750	1250	NP
ISU	UL	2590	1850	1350	860	1300	1190	860	920	NP
PFRB	UL	2250	2000	1750	1000	1750	1250	1000	1000	NP
Theory	UL	2880	2070	1520	980	1460	1340	980	1040	NP
R-2,3										
IITRI	*	*	*	*	*	*	*	*	*	*
ISO	UL	UL	3000	2500	1750	3250	3250	2500	3500	2250
ISU	UL	UL	2460	1440	2760	1380	1270	2760	980	1440
PFRB	UL	UL	2250	1750	1250	1750	1750	1250	1250	750
Theory	UL	UL	2740	1620	3070	1550	1430	3070	1210	1300
S-1										
IITRI	UL	UL	3380	2980	3270	2910	2770	3380	2710	1530
ISO	UL	UL	4250	3000	2000	3500	3000	2250	3500	1750
ISU	UL	UL	2040	1260	2020	1210	1110	2020	1070	500
PFRB	UL	UL	2000	1750	1250	1750	1250	1250	1250	750
Theory	UL	UL	2408	1520	2510	1470	1350	2390	1310	650

Table 5.12 Fire Flows for Maximum Height and Area Buildings Allowed by:

AIA

Occupancy	FR A	FR B	PLC	HT	Ord	ULC	WF
Business							
IITRI	UL	UL	3170	NP	NP	NP	NP
ISO	UL	UL	2250	NP	NP	NP	NP
ISU	UL	UL	1440	NP	NP	NP	NP
PFRB	UL	UL	1750	NP	NP	NP	NP
Theory	UL	UL	1620	NP	NP	NP	NP
Educational, Industrial, Mercantile							
IITRI	UL	UL	3170	2530	2590	3350	3170
ISO	UL	UL	3000	3500	2750	2000	3000
ISU	UL	UL	1440	960	2880	2160	1440
PFRB	UL	UL	1750	1250	1250	1250	750
Theory	UL	UL	1730	1180	3360	2550	1730
Health-Care							
IITRI	UL	UL	3350	NP	NP	NP	NP
ISO	UL	UL	1500	NP	NP	NP	NP
ISU	UL	UL	2160	NP	NP	NP	NP
PFRB	UL	UL	1500	NP	NP	NP	NP
Theory	UL	UL	2410	NP	NP	NP	NP
High Hazard							
IITRI	UL	UL	3170	NP	NP	2050	NP
ISO	UL	UL	2750	NP	NP	1250	NP
ISU	UL	UL	1440	NP	NP	720	NP
PFRB	UL	UL	2000	NP	NP	1250	NP
Theory	UL	UL	1730	NP	NP	900	NP
Residential							
IITRI	*	*	*	*	*	*	*
ISO	UL	UL	2000	2000	2000	1500	2000
ISU	UL	UL	1440	960	2160	2160	960
PFRB	UL	UL	1750	1250	1250	1250	750
Theory	UL	UL	1620	1090	2410	2410	1090
Storage							
IITRI	UL	UL	3170	2530	3200	3370	3370
ISO	UL	UL	3000	3500	2500	1750	3250
ISU	UL	UL	1440	960	2400	1800	1800
PFRB	UL	UL	1750	1250	1250	1250	1250
Theory	UL	UL	1730	1180	2820	2140	2140

Table 5.13 Fire Flows for Maximum Height and Area Buildings Allowed by:

SBCC

Occupancy	Type of Construction I	II	III	IV Prot.	IV Unprot.	V Prot.	V Unprot.	VI Prot.	VI Unprot.
A-2									
IITRI	UL	UL	3170	3170	2530	3170	2530	NP	NP
ISO	UL	UL	2000	1500	1250	2000	1500	NP	NP
ISU	UL	UL	1440	1440	960	1440	960	NP	NP
PFRB	UL	UL	1250	1250	1000	1250	1000	NP	NP
Theory	UL	UL	1730	1730	1180	1730	1180	NP	NP
B									
IITRI	UL	UL	NP	NP	NP	NP	NP	NP	NP
ISO	UL	UL	NP	NP	NP	NP	NP	NP	NP
ISU	UL	UL	NP	NP	NP	NP	NP	NP	NP
PFRB	UL	UL	NP	NP	NP	NP	NP	NP	NP
Theory	UL	UL	NP	NP	NP	NP	NP	NP	NP
H									
IITRI	3110	2590	2420	1770	1770	1770	1770	NP	NP
ISO	1500	1250	750	750	750	750	750	NP	NP
ISU	1380	960	900	600	600	600	600	NP	NP
PFRB	1250	1250	1250	1250	1250	1250	1250	NP	NP
Theory	1660	1220	1110	760	760	760	760	NP	NP
F									
IITRI	UL	UL	*	*	*	2870	900	3370	1270
ISO	UL	UL	4500	3500	3000	3000	2500	2250	1750
ISU	UL	UL	3780	3780	5040	2700	3600	1800	1200
PFRB	UL	UL	2250	2250	2000	2000	2000	1500	1250
Theory	UL	UL	4370	4370	5780	3160	4170	2140	1460
I									
IITRI	UL	UL	2590	3090	NP	3090	NP	2870	NP
ISO	UL	UL	2000	1500	NP	2000	NP	2000	NP
ISU	UL	UL	2880	2520	NP	2520	NP	2700	NP
PFRB	UL	UL	2250	2250	NP	2250	NP	1750	NP
Theory	UL	UL	3200	2810	NP	2810	NP	3000	NP
M									
IITRI	3370	3370	3300	3300	3350	3350	3350	2730	3170
ISO	2250	2250	4750	3750	2000	4750	2500	3500	3000
ISU	1800	1800	1620	1620	2160	1620	2160	1080	1440
PFRB	2000	2000	1750	1750	1250	1750	1250	1250	1250
Theory	2140	2140	1940	1940	2550	1940	2550	1320	1730
R									
IITRI	UL	UL	*	*	*	*	*	*	*
ISO	UL	UL	3250	3000	2000	3500	2750	3500	2500
ISU	UL	UL	2160	2160	4320	2160	4329	1260	1680
PFRB	UL	UL	2000	2000	1750	2000	1750	1750	1250
Theory	UL	UL	2410	2410	4780	2410	4780	1420	1880
S									
IITRI	UL	900	2590	2590	*	2590	*	2730	2050
ISO	UL	4500	4000	2500	2000	4000	3250	2500	2000
ISU	UL	3600	2880	2880	3840	2880	3840	1080	720
PFRB	UL	2500	2250	2250	2000	2250	2000	1000	1000
Theory	UL	4170	3360	3360	4440	3360	4440	1320	900

* Specified limit exceeded

Table 3.14 Fire Flows for Maximum Height and Area Buildings Allowed by:

ICBO

Occupancy	Type of Construction I	II FR	II 1 hr	II N	III 1 hr	III N	IV	V 1 hr	V N
A Div 3									
IITRI	UL	2870	2920	2260	2920	2260	2920	2510	1630
ISO	UL	2250	2000	1250	2500	1500	2500	3500	1750
ISU	UL	2700	1210	820	1210	820	1210	950	340
PFRB	UL	1250	1250	750	1750	750	1750	1250	750
Theory	UL	3000	1470	1010	1470	1020	1470	1170	690
B Div 2 (High-Rise)									
IITRI	UL	900	NP	NP	NP	NP	NP	NP	NP
ISO	UL	3530	NP	NP	NP	NP	NP	NP	NP
ISU	UL	3600	NP	NP	NP	NP	NP	NP	NP
PFRB	UL	1250	NP	NP	NP	NP	NP	NP	NP
Theory	UL	4170	NP	NP	NP	NP	NP	NP	NP
B Div 2									
IITRI	UL	900	3300	3350	3300	3350	3300	2980	3170
ISO	UL	3500	2250	2000	3000	2500	3000	4000	3000
ISU	UL	3600	1620	2160	1620	2160	1620	1260	1440
PFRB	UL	1250	1750	1250	1750	1250	1750	1750	1250
Theory	UL	4170	1940	2550	1940	2550	1940	1520	1730
H Div 3									
IITRI	UL	3310	2610	1940	2610	1940	2610	2210	1410
ISO	UL	2500	2250	1250	2750	1500	2750	3750	2250
ISU	UL	2230	1010	670	1010	670	1010	790	450
PFRB	UL	2500	1500	1250	1500	1250	1500	1500	750
Theory	UL	2630	1230	840	1230	840	1230	980	590
I Div 1									
IITRI	UL	3090	1800	NP	1800	NP	1800	1440	NP
ISO	UL	750	500	NP	750	NP	750	1000	NP
ISU	UL	1350	610	NP	610	NP	610	470	NP
PFRB	UL	1750	1000	NP	1000	NP	1000	750	NP
Theory	UL	1520	700	NP	700	NP	700	540	NP
R Div 1									
IITRI	UL	*	*	*	*	*	*	*	430
ISO	UL	2250	1500	1250	2000	1500	2000	2750	2000
ISU	UL	2700	2500	2500	2500	2500	2500	950	1080
PFRB	UL	1250	1750	1250	1750	1250	1750	1250	750
Theory	UL	3160	1370	1830	1370	1830	1370	1170	1220
R Div 3									
IITRI	UL	UL	UL	UL	UL	UL	UL	UL	UL
ISO	UL	UL	UL	UL	UL	UL	UL	UL	UL
ISU	UL	UL	UL	UL	UL	UL	UL	UL	UL
PFRB	UL	UL	UL	UL	UL	UL	UL	UL	UL
Theory	UL	UL	UL	UL	UL	UL	UL	UL	UL

these ranges are examined to investigate the key parameter(s) affecting fire flow requirements.

5.4.1 Fire Flow Calculation Techniques

Intuitively, one would expect that the calculation technique may effect the resulting requirement. Whereas, the techniques should at least agree on the order of magnitude of the fire flow, because of the differing methodologies and intricacies of the techniques they cannot be expected to yield identical results.

Generally, the techniques do produce similar results and in all cases do not differ by more than a factor of five. However, in relation to a water distribution system, 1,000 g.p.m. is significantly less than 5,000 g.p.m., thus variation only by a factor of five is observed to be quite substantial.

Thus, the calculation technique definitely affects the resulting requirement. Upon a preliminary examination of Tables 5.11-5.14, one method does not always appear to produce the highest or lowest fire flow requirement. However, upon performing a more in-depth analysis, the following observation is made: 49 percent of the maximum fire flow requirements for a particular occupancy and construction type are derived from the IITRI technique, 35 percent from ISO and 13 percent from the Theory. The lowest requirements are distributed as follows: 48 percent by ISU, 32 percent by PFRB and 14 percent by ISO.

The techniques by IITRI, ISU and the Theory all utilize the total floor area of the building, implicitly assuming it is completely involved in fire. This assumption would appear to continually yield high requirements, which is the case for IITRI, however, the large frequency of low requirements by ISU is not expected.

5.4.2 Construction Type

Type of construction intuitively would be expected to affect fire flow requirements, e.g. more water is used on fully-involved wood frame than fire resistive buildings of the same occupancy class since the structural members are combustible

and wood frame buildings generally are not well compartmented with fire resistance rated partitions. However, the building codes limit the size of buildings according to the construction type, thereby possibly counteracting the affect of construction type on fire flow requirements.

Examination of the tables indicates that fire flow requirements appear to be affected by the type of construction for a particular occupancy - however in the opposite manner than expected. For a particular occupancy and for a particular calculation technique, fire flow requirements have a decreasing trend, proceeding from left to right in the tables, i.e. from fire-resistive to wood frame construction.

5.4.3 Building Code

Selection of apparticular model building code instead of the others may also be expected to affect fire flow requirements. Table 5.15 presents the range of fire flows determined by a particular technique for all permitted construction type of each selected occupancy class.

Since the upper portion of the range is unlimited in most cases (due to unlimited areas permitted for some construction types), this analysis can concentrate only on the lower part of the range, i.e. the minimum fire flow requirements for the occupancy by a particular technique for a given model code. The highest minima were derived from height and area limits proposed by ICBO in 40 percent of the cases, SBCC in 32 percent of the cases. Lowest minima were derived from the limits proposed by BOCA and AIA in 33 percent of the cases (each) and in 24 percent of the cases by ICBO.

This indicates that the building codes may affect fire flow requirement ranges, however one code is not clearly dominant in allowing larger buildings thereby having consistently higher fire flow requirements or conversely in being overly restrictive to have only lesser fire flow requirements.

Table 5.15 Range of Fire Flows: Code vs. Fire Flow Calculation Technique

	BOCA	AIA	SBCC	ICBO
Hospital				
IITRI	2450-UL	3350-UL	2590-UL	1440-UL
ISO	750-UL	1500-UL	1500-UL	750-UL
ISU	860-UL	2160-UL	2520-UL	470-UL
PFRB	1000-UL	1500-UL	1750-UL	750-UL
Theory	980-UL	2410-UL	2810-UL	540-UL
High-Rise Office				
IITRI	2220-UL	3170-UL	UL	900-UL
ISO	4500-UL	2250-UL	UL	2520-UL
ISU	3078-UL	1440-UL	UL	3600-UL
PFRB	2250-UL	1750-UL	UL	1250-UL
Theory	3420-UL	1620-UL	UL	4170-UL
Furniture Warehouse				
IITRI	1530-UL	2530-UL	900-UL	900-UL
ISO	1750-UL	1750-UL	2000-UL	2000-UL
ISU	500-UL	960-UL	720-UL	1260-UL
PFRB	750-UL	1250-UL	1000-UL	1250-UL
Theory	650-UL	1180-UL	900-UL	1520-UL
Mattress Factory				
IITRI	1720-3390	2050-UL	900-UL	1410-UL
ISO	750-2000	1250-UL	1750-UL	1250-UL
ISU	580-2020	720-UL	1200-UL	450-UL
PFRB	750-2500	1250-UL	1250-UL	750-UL
Theory	730-2390	900-UL	1460-UL	590-UL
Department Store				
IITRI	1720-UL	2590-UL	2730-3370	900-UL
ISO	2000-UL	2000-UL	2000-4750	2000-UL
ISU	580-UL	960-UL	1440-2160	1260-UL
PFRB	750-UL	750-UL	1250-2000	1250-UL
Theory	730-UL	1180-UL	1320-2550	1520-UL
Library				
IITRI	1530-UL	2590-UL	2530-UL	1630-UL
ISO	1750-UL	2000-UL	1250-UL	1250-UL
ISU	500-UL	960-UL	960-UL	540-UL
PFRB	750-UL	750-UL	1000-UL	750-UL
Theory	650-UL	1180-UL	1180-UL	690-UL
Detached Single Family Dwelling				
IITRI	*	*	*	UL
ISO	2250-UL	1500-UL	2000-UL	UL
ISU	980-UL	960-UL	1260-UL	UL
PFRB	750-UL	750-UL	1250-UL	UL
Theory	1110-UL	1090-UL	1420-UL	UL
Attached Single Family Dwelling				
IITRI	*	*	*	UL
ISO	2750-UL	2000-UL	2500-UL	UL
ISU	980-UL	960-UL	1260-UL	UL
PFRB	750-UL	750-UL	1250-UL	UL
Theory	1110-UL	1090-UL	1420-UL	UL

Garden Apartment	BOCA	AIA	SBCC	ICBO
IITRI	*	*	*	430-*
ISO	2250-UL	1500-UL	2000-UL	1250-UL
ISU	980-UL	960-UL	1260-UL	950-UL
PFRB	750-UL	750-UL	1250-UL	750-UL
Theory	1110-UL	1090-UL	1420-UL	1170-UL
Rolled Paper Warehouse				
IITRI	1530-UL	2530-UL	900-UL	900-UL
ISO	1750-UL	1750-UL	2000-UL	2000-UL
ISU	500-UL	960-UL	720-UL	1260-UL
PFRB	750-UL	1250-UL	1000-UL	1250-UL
Theory	650-UL	1180-UL	900-UL	1520-UL
High Density Residential				
IITRI	*	*	*	UL
ISO	2250-UL	2000-UL	2500-UL	UL
ISU	980-UL	960-UL	1260-UL	UL
PFRB	750-UL	750-UL	1250-UL	UL
Theory	1110-UL	1090-UL	1420-UL	UL
Medium Density Residential				
IITRI	*	*	*	UL
ISO	2000-UL	1750-UL	2250-UL	UL
ISU	980-UL	960-UL	1260-UL	UL
PFRB	750-UL	750-UL	1250-UL	UL
Theory	1110-UL	1090-UL	1420-UL	UL
Low Density Residential				
IITRI	*	*	*	UL
ISO	2250-UL	1500-UL	2000-UL	UL
ISU	980-UL	960-UL	1260-UL	UL
PFRB	750-UL	750-UL	1250-UL	UL
Theory	1110-UL	1090-UL	1420-UL	UL
Detached Commercial				
IITRI	1720-UL	2590-UL	2730-3370	900-UL
ISO	2250-UL	2250-UL	2250-6000	2250-UL
ISU	580-UL	960-UL	1440-2160	1260-UL
PFRB	750-UL	750-UL	1250-2000	1250-UL
Theory	730-UL	1180-UL	1320-2550	1520-UL
Industrial Park				
IITRI	1720-UL	2590-UL	900-UL	900-UL
ISO	2250-UL	2250-UL	2000-UL	2250-UL
ISU	580-UL	2000-UL	1200-UL	1260-UL
PFRB	750-UL	960-UL	1250-UL	1250-UL
Theory	730-UL	750-UL	1460-UL	1520-UL

TABLE 5.16 RANGE OF FIRE FLOWS: CONSTRUCTION TYPE VS. CODE

	Occupancy Class	Fire Resistive A	Fire Resistive B	Non-Combustible Prot. A	Non-Combustible Prot. B	Non-Combustible Unprot.	Heavy Timber	Ordinary Prot.	Ordinary Unprot.	Wood Frame Prot.	Wood Frame Unprot.
Hospital											
BOCA	I-2	UL	1600-3010	1750-3380	1250-3080	750-4500	1300-3020	1190-2880	750-4500	920-2450	NP
AIA	Health-Care	UL	UL	1500-3350	NA	NP	NP	NP	NA	NP	NA
SBCC	I	UL	NA	UL	1500-3090	NP	2000-3200	2000-3090	NP	1750-3000	NP
ICBO	I Div 1	UL	NA	750-3090	500-1810	NP	610-1800	610-1800	NP	470-1440	NP
High-Rise Office											
BOCA	B	UL	UL	2220-4500	NP	NP	NP	NP	NP	NP	NP
AIA	Business	UL	UL	1440-3170	NA	NP	NP	NP	NA	NP	NA
SBCC	B	UL	NA	UL	NP	NP	NP	NP	NP	NP	NP
ICBO	B Div 2	UL	NA	900-4170	NP	NP	NP	NP	NP	NP	NP
Furniture Warehouse											
BOCA	S-1	UL	UL	2000-4250	1260-3000	1250-3270	1210-3500	1110-3000	1250-3380	1070-3500	500-1750
AIA	Storage	UL	UL	1440-3170	NA	1250-3370	960-3500	1250-3200	NA	1250-3370	NA
SBCC	S	UL	NA	900-4500	2250-3360	2000-4440	2250-4000	2250-4000	2000-4440	1000-2730	720-2050
ICBO	B Div 2	UL	NA	900-4170	1620-3300	1250-3350	1620-3390	1250-3350	1620-3300	1260-4000	1250-3170
Mattress Factory											
BOCA	H	2000-3390	1500-3350	1500-3920	900-2420	590-1720	960-2250	790-2210	580-1720	610-1800	NP
AIA	High Hazard	UL	UL	1440-3170	NA	720-2050	NP	NP	NA	NP	NA
SBCC	H	1250-3110	NA	960-2530	600-1770	600-1770	750-2420	600-1770	600-1770	NP	NP
ICBO	H Div 3	UL	NA	2230-3310	1010-2610	670-1940	1010-2750	1010-2750	670-1940	790-3750	450-2250
Department Store and Shopping Center											
BOCA	M	UL	UL	2000-4750	1440-3250	1250-3270	1380-4250	1270-3750	1250-3270	1220-3750	580-2000
AIA	Mercantile	UL	UL	1440-3170	NA	1250-3350	960-3500	1250-3360	NA	750-3170	NA
SBCC	M	1800-3370	NA	1860-3370	1620-3750	1250-3350	1620-4750	1620-4750	1250-3250	1060-3500	1250-3170
ICBO	B Div 2	UL	NA	900-4170	1620-3300	1250-3350	1620-3360	1620-3300	1250-3350	1260-4000	1250-3170
Library											
BOCA	A-3	UL	UL	2000-4250	1260-2980	1250-3380	1210-3250	1110-3000	1250-3380	1090-2710	500-1750
AIA	Educational	UL	UL	1440-3170	NA	1250-3350	960-3500	1250-3360	NA	750-3170	NA
SBCC	A-2	UL	NA	UL	1250-3170	960-2530	1250-3170	1250-3170	960-2530	NP	NP
ICBO	A Div 3	UL	NA	1250-3000	1210-3920	750-2260	1210-2920	1210-2920	750-2260	950-3000	540-1750
Detached Single Family Dwelling											
BOCA	R-4	UL	UL	2250-3000	1440-2560	1250-3070	1380-3250	1270-3250	1250-2760	980-3500	750-2250
AIA	Residential	UL	UL	1440-2000	NA	1250-2410	960-2000	1250-2160	NA	750-2000	NA
SBCC	R	UL	NA	UL	2000-3000	1750-4320	2000-3250	2000-3500	1750-4320	1260-3500	1250-3500
ICBO	R Div 3	UL	NA	UL	UL	UL	UL	UL	UL	UL	UL

	Occupancy Class	Fire Resistive A	Fire Resistive B	Non-Combustible Prot. A	Non-Combustible Prot. B	Non-Combustible Unprot.	Heavy Timber	Ordinary Prot.	Ordinary Unprot.	Wood Frame Prot.	Wood Frame Unprot.
Attached Single Family Dwelling (Townhouse) (exposure charge for ISO)											
BOCA	R-3	UL	UL	2250-3750	1440-3000	1250-3760	1380-4000	1270-4000	1250-3000	980-4250	750-2750
AIA	Residential	UL	UL	1440-2500	NA	1250-2410	960-2500	1250-2500	NA	750-2500	NA
SBCC	R	UL	NA	UL	2000-3750	1750-4320	2000-4000	2000-4250	1750-4320	1260-4250	1250-3000
ICBO	R Div 3	UL	NA	UL	UL	UL	UL	UL	UL	UL	UL
Garden Apartment											
BOCA	R-2	UL	UL	2250-3000	1440-2500	1250-3070	1380-3250	1270-3250	1250-2760	980-3500	750-2250
AIA	Residential	UL	UL	1440-2000	NA	1250-2410	960-2000	1250-2160	NA	750-2000	NA
SBCC	R	UL	NA	UL	2000-3000	1750-4320	2000-3250	2000-3500	1750-4320	1260-3500	1250-3500
ICBO	R Div 1	UL	NA	1250-3160	1370-2500	1250-2500	1370-2500	1370-2500	1250-2500	950-2750	630-2000
Rolled Paper Warehouse											
BOCA	S-1	UL	UL	2000-4250	1260-3000	1250-3270	1210-3500	1110-3000	1250-3380	1070-3500	500-1750
AIA	Storage	UL	UL	1440-3170	NA	1250-3370	960-3500	1250-3200	NA	1250-3370	NA
SBCC	S	UL	NA	900-4500	2250-3360	2000-4440	2250-4000	2250-4000	2000-4440	1000-2730	720-2050
ICBO	B Div 2	UL	NA	900-4170	1620-3300	1250-3350	1620-3300	1620-3300	1250-3350	1260-4000	1250-3170
High Density Residential											
BOCA	R-3	UL	UL	2250-3750	1440-3000	1250-2760	1380-4000	1270-4000	1250-3000	980-4250	750-2750
AIA	Residential	UL	UL	1440-2500	NA	1250-2410	960-2500	1250-2500	NA	750-2500	NA
SBCC	R	UL	NA	UL	2000-3750	1750-4320	2000-4000	2000-4250	1750-4320	1260-4250	1250-3000
ICBO	R Div 3	UL	NA	UL	UL	UL	UL	UL	UL	UL	UL
Medium Density Residential											
BOCA	R-4	UL	UL	2250-3200	1440-2750	1250-3070	1380-3500	1270-3500	1250-2760	980-4000	750-2500
AIA	Residential	UL	UL	1440-2000	NA	1250-2410	960-2000	1250-2160	NA	750-2000	NA
SBCC	R	UL	NA	UL	2000-3000	1750-4320	2000-3250	2000-3500	1750-4320	1260-3500	1250-2750
ICBO	R Div 3	UL	NA	UL	UL	UL	UL	UL	UL	UL	UL
Low Density Residential											
BOCA	R-4	UL	UL	2250-3000	1440-2500	1250-3070	1380-3250	1270-3250	1250-2760	980-3500	750-2250
AIA	Residential	UL	UL	1440-2000	NA	1250-2410	960-2000	1250-2160	NA	750-2000	NA
SBCC	R	UL	NA	UL	2000-3000	1750-4320	2000-3250	2000-3500	1750-4320	1260-3500	1250-3500
ICBO	R Div 3	UL	NA	UL	UL	UL	UL	UL	UL	UL	UL
Detached Commercial											
BOCA	M	UL	UL	2000-5500	1440-4000	1250-3270	1380-5250	1270-4250	1250-3750	1220-4500	580-2500
AIA	Mercantile	UL	UL	1440-3500	NA	1250-3350	960-4250	1250-3360	NA	750-3500	NA
SBCC	M	1800-3370	NA	1800-3370	1620-4500	1250-3350	1620-5500	1620-5500	1250-3350	1080-4250	1250-3500
ICBO	B Div 2	UL	NA	900-4250	1620-3300	1250-3350	1620-3500	1620-3500	1250-3350	1260-4750	1250-3500
Industrial Park											
BOCA	F	UL	UL	2000-5250	1440-3750	1250-3270	1380-4750	1270-4250	1250-3500	1270-4250	580-2250
AIA	Industrial	UL	UL	1440-3250	NA	1250-3350	960-4000	1250-3360	NA	750-3250	NA
SBCC	F	UL	NA	UL	2250-3780	2000-5040	2250-5000	2000-3500	2000-3600	1500-3570	1200-2000
ICBO	B Div 2	UL	NA	900-4170	1620-3300	1250-3350	1620-3300	1620-3300	1250-3350	1260-4500	1250-3250

In Table 5.16, the range of fire flows as required by the five techniques are presented by each occupancy class, type of construction and the four model codes. Examination of Table 5.16 results in the following observations, noted below.

1. The AIA code has the most "NP" entrees, thereby prohibiting, rather than simply limiting certain occupancy class and construction type combinations.
2. The minima and maxima for each range of flows appear to be greatest for those associated with the SBCC code for a particular occupancy and construction type. The lowest minima and maxima appear to involve application of the AIA code.

Thus, in the two separate analysis from Tables 5.15 and 5.16 involving the building codes, the SBCC code allows buildings to be constructed with associated higher fire flow requirements, compared to the other model codes. Conversely, the AIA code regulates the construction of buildings to yield lower fire flow requirements.

5.5 Conclusions

Fire flow requirements derived for largest permissible structures according to the four model building codes are affected by several variables, including occupancy, regulating building code, calculation technique and construction type. Because of the limitations in area of buildings of construction types permitting use of combustible structural elements, fire flow requirements do not appear to be strongly dependent on the construction type. The more hazardous occupancies have some of the higher required fire flows, however more stringent building code requirements for more hazardous occupancies again appears to lessen the affect of this variable.

The analysis does indicate fire flow requirements to be strongly dependent

on the regulating building code and on the calculation technique for determining fire flow.

5.6 Water for Domestic Requirements

Community water requirements are based upon two demands: 1) consumer consumption and, 2) water supply for fire protection. The primary focus of this study is adequate water supply for fire protection. However, the literature on water supply requirements is almost silent on the interrelationship of water supply requirements for both demand functions. Consequently an important question can be raised: For any given building or building complex how does the water demand requirement for domestic consumption relate to fire flow demand? In other words if fire flow demand is met will consumer consumption requirements be met; or vice versa. The answer to this concern could have important implications for the design of municipal water system and building code criteria.

The above question may be addressed by examining the criteria for domestic or consumer consumption requirements. Ameen draws from a number of literature sources including the American Water Works Association, Cast Iron Pipe Research Association, North Carolina Water Association, American Public Health Association and the notes from several distinguished professors in Civil Engineering in establishing basic criteria and guidelines for estimating water supply requirements (45). The basic concepts established by Ameen follow.

The consumer water requirements for a community water system are the total of the combined water requirements for domestic population, commercial and industrial, and institutional usage. Industrial process water requirements require special analysis. Process requirements should be established from case studies at a particular facility or from charted demand requirements at a similar facility. It should be noted that in many cases, industrial requirements for processing will exceed the total

requirement of the entire community.

In determining domestic requirements, the basis for calculations may best be obtained from an estimate of population. Rather than try to obtain an actual count of population to be served, it is much more convenient to estimate the population on the basis of per dwelling unit from established criteria of population trends. Total Estimated Population = Population Density (see Table 5.17) X Area Developed or To be Developed. An alternative method is to estimate the number of dwellings per area from average lot size (see Table 5.18). A third element is needed to refine the estimates. Domestic population can be determined from examining the type of dwelling and the estimated number of persons per dwelling type. Table 5.19 provides the basic information for this type of estimation. The figures in the indicated Tables are based upon average values obtained from a community study for various types of dwellings.

In determining domestic water usage, two alternative considerations need to be evaluated. First the daily usage must be based upon the maximum day of the week so that this quantity of water will be available for the community at all times. The maximum quantity of water necessary to furnish the need of the community will depend upon whether or not the system is metered. A system which is not metered will have a demand for water as great as 300 per cent of that community which is metered. For calculation purposes, the following values are accepted in current practice (1979) for water consumption for domestic populations.

Metered Services.	140 gallons daily consumption per person
Unmetered Services.	210 gallons daily consumption per person

TABLE 5.17 Population Densities from Average Lot Area (45, p. 7)

Average Area of Lot Within Development in Square Feet	Estimated Population Per Acre	Estimated Population Per Square Mile
10,000	6.25	4,160
15,000	4.2	2,688
20,000	3.15	2,016
25,000	2.52	1,612
30,000	2.10	1,344
40,000	1.28	819
50,000	1.16	742
60,000	1.05	672
70,000	0.90	576
80,000	0.79	514

TABLE 5.18 Estimated Number of Dwellings Per Area from Average Lot Size (45, p. 8)

Average Lot Area in Square Feet	Estimated Number of Dwellings Per Acre	Estimated Number of Dwellings Per Square Mile
10,000	1.56	1,040
15,000	1.05	672
20,000	.78	504
25,000	.63	403
30,000	.52	336
40,000	.32	204
50,000	.29	186
60,000	.26	167
70,000	.22	144
80,000	.19	121

TABLE 5.19 Estimating Domestic Populations (45, p. 9)

Type of Dwelling	Estimated Persons Per Dwelling
First-Class	4
Multi-Dwelling	
One Bedroom Unit	2
Two Bedroom Unit	3
Three Bedroom Unit	5
Mobile Home	2½

Water supply requirements for institutions may also be determined on the population basis as above. Such water consumption figures should be based upon the <u>future</u> enrollment of the school or institution, and upon future plans concerning changes in status of the type of the institution. Table 5.20 suggests criteria on the per student or person basis and relates the type of institution to be served with this per person water usage.

Commercial and industrial water usage must be calculated on some other basis rather than either the patronage or per person usage because it is impossible to predict with any degree of accuracy the potential success of the establishment. Therefore, Table 5.21 has been developed to not only set forth criteria for water consumption, but also to simplify the basic method of calculating such requirements.

Upon the basis of water usage as given in Table 5.21, the total daily water consumption can be calculated.

The total water requirement for a community would be the total as calculated, combining information from Tables 5.19 through 5.22. The same set of referenced Tables can be used to calculate the requirements for a specific building or building complex; alternative calculations might focus on a block or defined segment of a community. Therefore, the actual water demand for consumer consumption could be compared and contrasted to the amount of water required for fire protection.

TABLE 5.20 Institutional Water Consumption (45, p. 10)

Type of Institution	Gallons Per Person Per Day
Boarding Schools, Elementary	75
Boarding Schools, Senior	100
Churches	5
Clubs, Country	25
Clubs, Civic	3
College, Day Students	25
College, Junior	100
College, Senior	100
Elementary Schools	16
Hospitals	400
Junior and High Schools	25
Nursing Homes	150
Prisons	60
Rooming Houses	100
Summer Camps	60

TABLE 5.21 Commercial and Industrial Water Consumption Requirements (45, p. 11)

Type of Establishment	Estimated Water Usage and Basis of Calculation
Barber Shop	100 gallons per day per chair
Beauty Shop	125 gallons per day per chair
Dentist Office	750 gallons per day per chair
Department Store*	40 gallons per day per employee
Drug Store	500 gallons per day
With Fountain Service	Add 1,200 to 1,500 gallons per day
Serving Meals	Add 50 gallons per day per seat
Industrial Plant**	30 gallons per day per employee
Laundry	2,000-5,000-20,000 gallons per day
Launderette	1,000 gallons per day per unit
Meat Market	5 gallons per day per 100 sq. ft. floor area
Motel or Hotel	125 gallons per day per room
Office Building*	12 gallons per day per 100 sq. ft. floor area or 25 gallons per employee
Physicians Office	200 gallons per day per examining room
Restaurant	20-50-120 gallons per day per seat
Single Service	500-1,500-2,500 gallons per day
Drive-in	20 gallons per day per car space
Service Station	600-1,000-1,500 gallons per day per wash rack
Theatre	3 gallons per day per seat
Drive-in	3 gallons per day per car space
Other Establishments***	500 gallons per day

*Including customer service.
**Not including process water.
***Non-water using establishments. 500 gallons per day should be considered the minimum daily usage for any establishment.

TABLE 5.22 Domestic Water Consumption (45, p. 9)

Type of System	Daily Consumption Per Person
All Metered Services	70-100-125 Gallons
Unmetered Services	100-150-250 Gallons

*The commonly accepted value for water usage for domestic populations is 100 gallons per day per person. Studies indicate that the combined average water usage for a community will vary from 69 to 109 gallons per person per day. Hence, for design of a community water system, the value of 125 gallons per day is the suggested value since it is a maximum per day usage per person.

TABLE 5.23 Instantaneous Water Demands for Residential Areas (45, p. 50)

Total Number of Residences Served	GPM Per Residence	Total Number of Residence Served	GPM Per Residence
5	8.0	90	2.1
10	5.0	100	2.0
20	4.3	150	1.6
30	3.8	200	1.3
40	3.4	300	1.2
50	3.0	400	0.9
60	2.7	500	0.8
70	2.5	750	0.7
80	2.2	1,000	0.6

TABLE 5.24 Instantaneous Water Demands for Commercial Areas (45, p. 51)

Type of Establishment	Basis of Flow Demand
Barber Shop	1.5 gpm per chair
Beauty Shop	1.5 gpm per chair
Dentist Office	2.0 gpm per chair
Department Store*	0.5-1.0-1.5 gpm per employee
Drug Store	3.0 gpm
With Fountain Service	add 3.0 gpm
Serving Meals	add 1.0 gpm per seat
Industrila Plant**	0.5 gpm per employee
Laundry	20.0-40.0-60.0 gpm
Launderette	5.0 gpm per unit
Meat Market, Super Market	1.0 gpm per 100 square feet floor area
Motel, Hotel	2.0 gpm per unit
Office Building*	0.2 gpm per 100 square feet floor area
Physician's Office	2.0 gpm per examining room
Restaurant	1.0 gpm per seat
Single Service	3.0-6.0-10.0 gpm
Drive-In	0.5-1.0-3.0 gpm per car space
Service Station	3.0-5.0-8.0 gpm per wash rack
Theatre	0.3-1.0-2.0 gpm per seat
Drive-In	0.4 gpm per car space
Other Establishments***	0.3-1.0-3.0 gpm per employee

*Including customer service.
**Not including process water.
***Non-water using establishments.

TABLE 5.25 Instantaneous Water Demands for Institutions (45, p. 52)

Type of Institution	Basis of Flow Demand
Boarding Schools, Colleges	1.0 gpm per student
Churches	0.2 gpm per member
Clubs, Civic	0.4 gpm per member
Clubs, Country	0.6 gpm per member
Hospitals	4.0 gpm per bed
Nursing Homes	2.0 gpm per bed
Prisons	1.0 gpm per prisoner
Rooming Houses	1.0 gpm per roomer
Summer Camps	0.2 gpm per camper

SCHOOLS: DAY, ELEMENTARY, JUNIOR, SENIOR

Number of Students	GPM Per Student	Number of Students	GPM Per Student
0-50	1.0	800	0.68
100	0.97	900	0.66
200	0.94	1,000	0.60
300	0.90	1,200	0.52
400	0.86	1,400	0.46
500	0.82	1,600	0.41
600	0.78	1,800	0.38
700	0.72	2,000	0.35

Water demand rates are translated into both water system delivery rates and water storage capacity. In other words, a certain amount of water must be stored to meet both the rate of flow delivery and the duration of flow delivery. The delivery system (pipe network) must have the capability of providing the "demand requirement" to the proper distribution point. The determine these interface requirements, a second domestic consumption factor is taken into account. Water demand varies according to time of day. Typically, water demand for consumer consumption peaks at two demand periods: 8 a.m. and 8 p.m. (45, p. 1).

The maximum instantaneous flow for a community occurs during one or both of the peak periods. The occurrence of instantaneous flows so greatly exceeds the average flows and requirements of the community that it is necessary to calculate these maximum or instantaneous flows within a community water system in order that storage and pumping facilities may be properly designated. Tables 5.23, 5.24 and 5.25 provide information and data by which these calculations may be made. These tables set forth criteria for instantaneous flow demands for residential, commercial, and institutional areas.

The flow demand of institutions must be considered in the light of the time for which the institution is used per day. For example day schools are operated for a period of six to eight hours per day while other institutions such as colleges and hospitals are operated for 24 hours. The flow demand with this consideration is given in Table 5.23.

Apartment buildings are to be evaluated as individual residential units within Table 5.25 and each apartment unit is thereby counted as a separate residence.

By considering the breakdown of the individual type of users in

accordance with the above tables, it is possible to determine the individual instantaneous flows and the total instantaneous flows required for a water system. This total instantaneous flow is the demand upon storage facilities which may be expected to occur instantaneously during a 24 hour period. The total average daily demand for water may be obtained from Table 5.19 through 5.22.

An example of determining total flow which would occur instantaneously within a community would be in the case of a water system which is to serve a community of 80 residences and a commercial center comprised of a ready-to-wear shop, a drug store which has fountain service, a television repair shop and a super market of 3,000 square feet of floor area. The breakdown of individual flows and the total instantaneous flow for this community, would be as follows:

80 Residences at 2.2 gpm per residence (Table 5.25)	176 gpm
1 Ready-to-wear shop at 1.0 gpm (Table 5.24)	1 gpm
1 Drug store (3.0 gpm) with fountain service (3.0 gpm) (Table 5.24)	6 gpm
1 Television repair shop at 1.0 gpm (Table 5.24)	1 gpm
1 Super Market at 1.0 gpm/100 sq. ft. x 3,000 sq. ft	30 gpm
Total Instantaneous Flow	214 gpm

Section VI of this study considers the water requirements for a selected group of representative occupancies for both fire protection purposes and consumer consumptions. Some relevant observations on the interrelationship of these two demands are made in the referenced section.

6. WATER SUPPLY REQUIREMENTS FOR CASE STUDY OCCUPANCIES AND COMPLEXES

Sixteen occupancies and building complexes have been described in the previous section relative to applicable building code requirements. In this section, a hypothetical building of each type is examined with respect to their water supply requirements for domestic use and fire protection.

6.1 The Selected Buildings

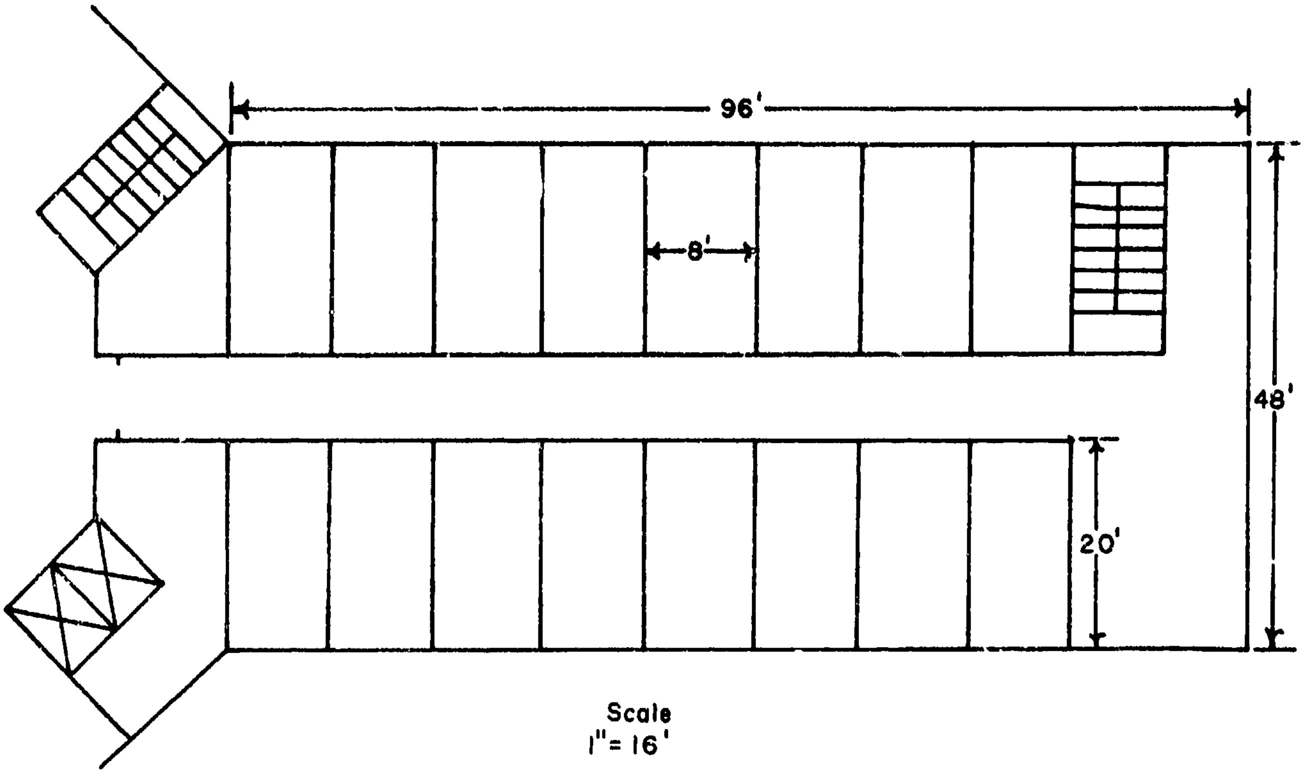
A basic floor plan of each of the sixteen buildings and complexes along with a general description for each is presented in figures 6.1 through 6.16. The descriptions are included to provide details on the proposed type of construction, protection features, etc., so that the water supply analysis can be performed. Any similarity of the selected buildings to actual buildings is coincidence, as the descriptions were developed from the experience of the research team with generic examples of the particular building or complex.

6.2 Fire Flow Requirements

The previously discussed five techniques for calculating fire flow are applied in this section to determine the water supply needed for fire protection purposes for the selected occupancies and complexes. The fire flow requirements are noted in Table 6.1.

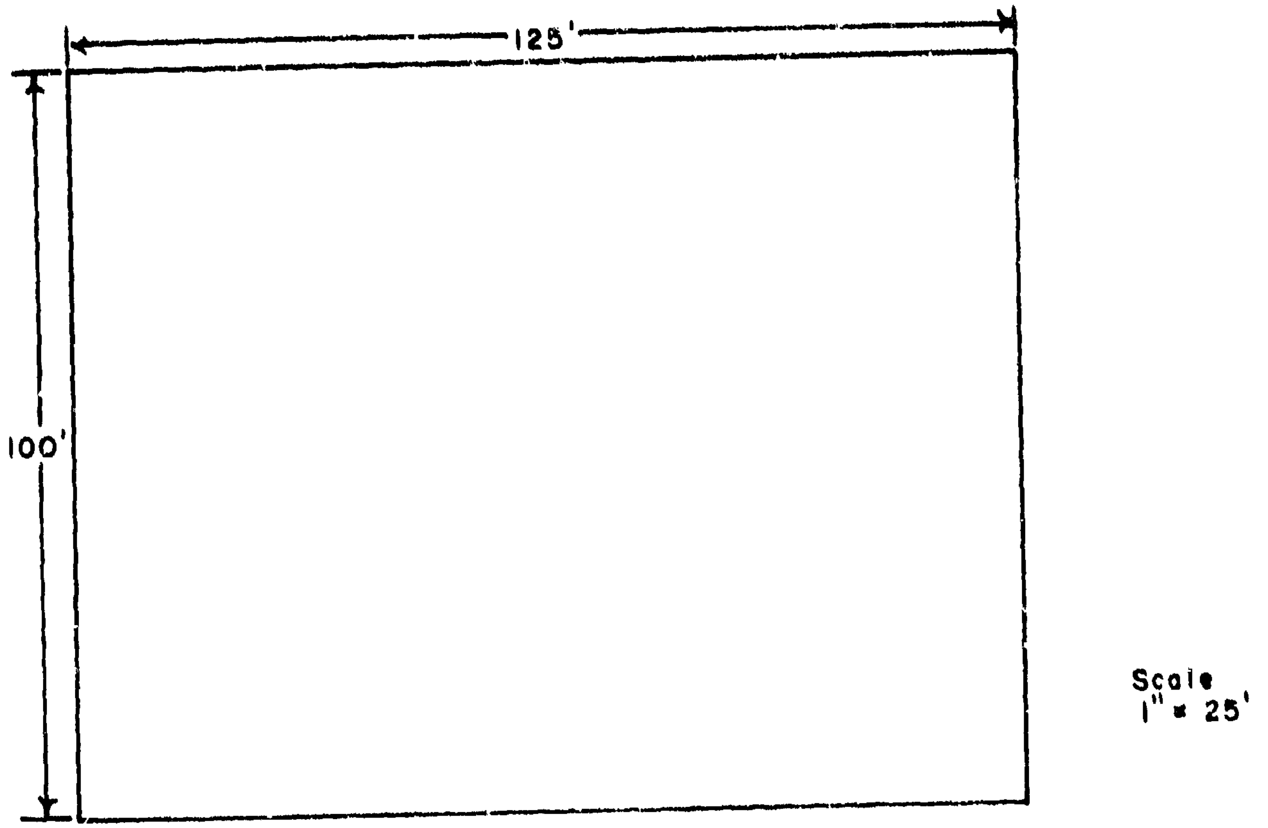
The required fire flows vary significantly for a particular case. The techniques considering the total area to be involved in fire are those identified as ISU and Theory. Each of these two techniques yield fire flow requirements exceeding 10,000 gpm for four of the selected cases, while other techniques for these same four cases are substantially less. In those four instances with extremely high fire flows, the other method considering the area to be completely involved in fire could not be applied as the floor area of the building exceeds the maximum permissible area by the technique.

Figure 6.1 Hospital Wing



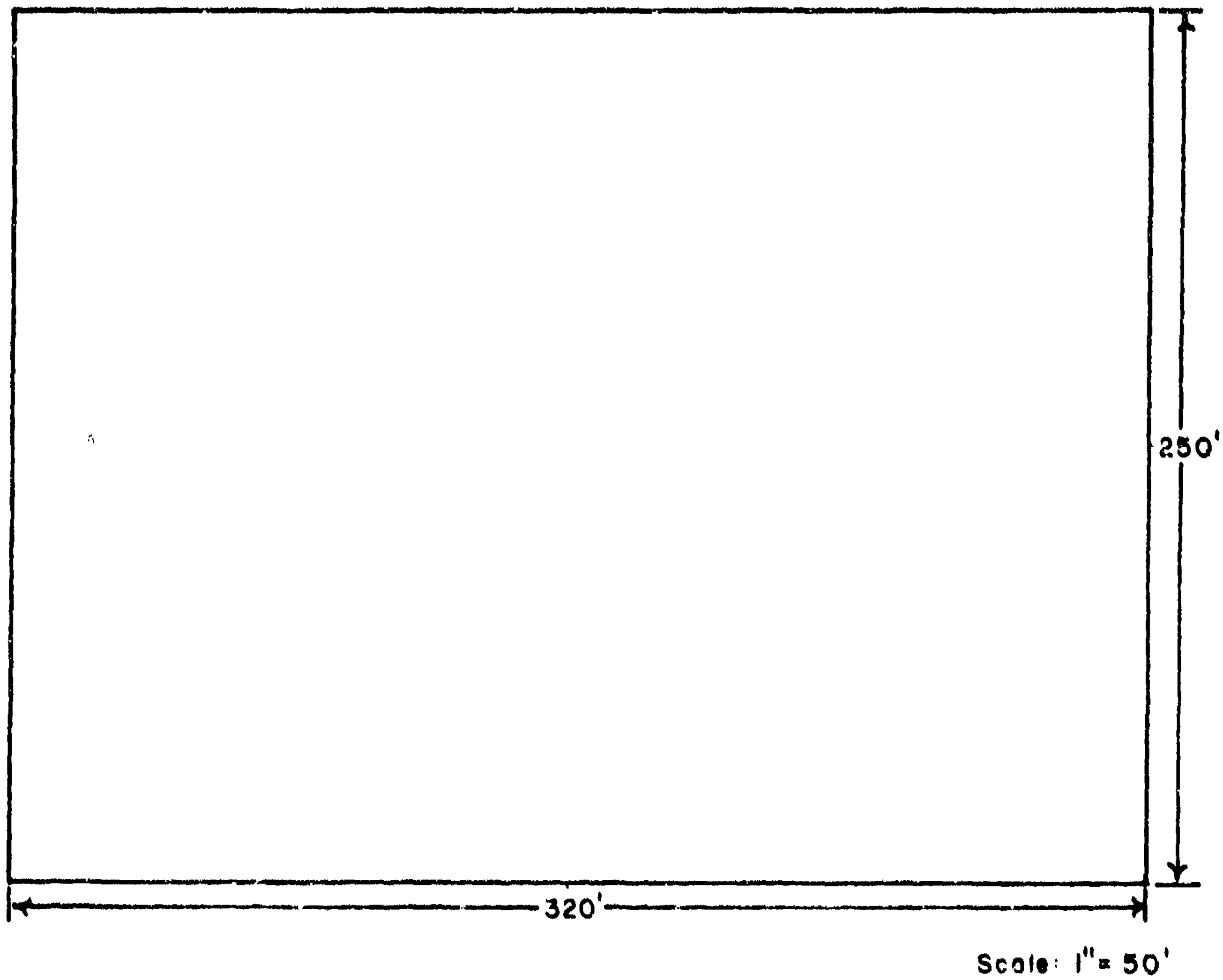
Construction: Fire Resistive
Height: 4 stories, 50 ft.
Area: 4,928 sq. ft. per wing per floor
Protection: None

Figure 6.2 High Rise Office



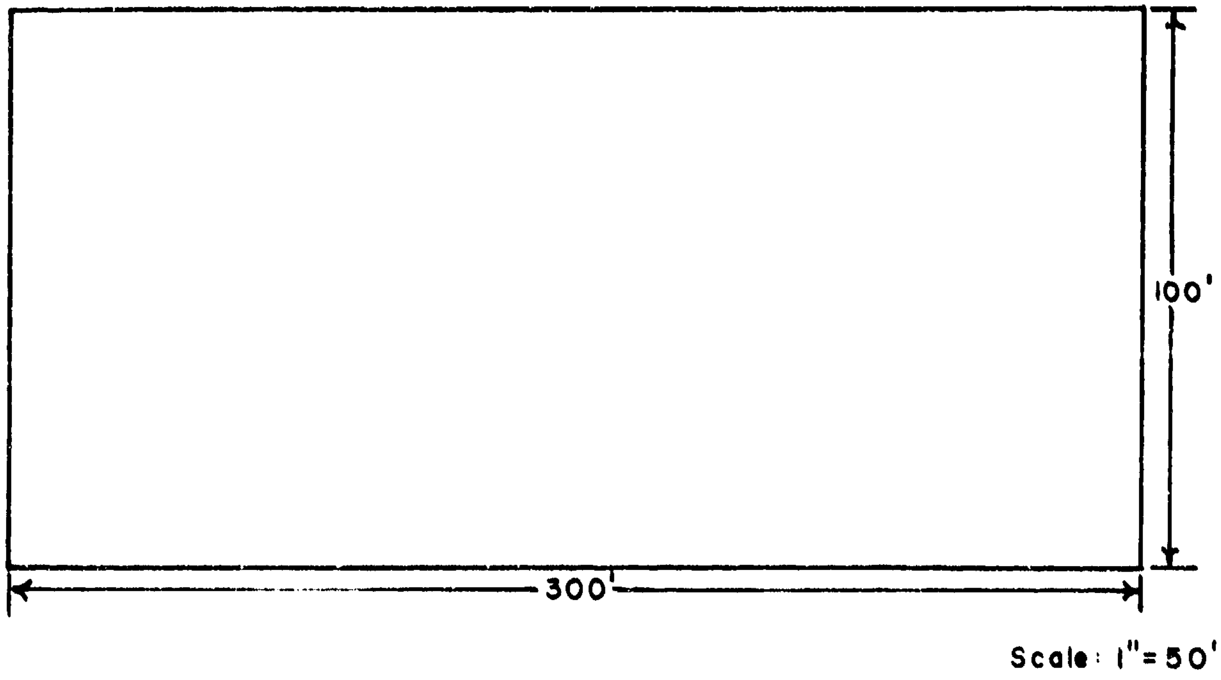
Construction: Fire Resistive
Height: 10 stories, 120 ft.
Area: 125,000 sq. ft. per floor
Protection: None

Figure 6.3 Furniture Warehouse



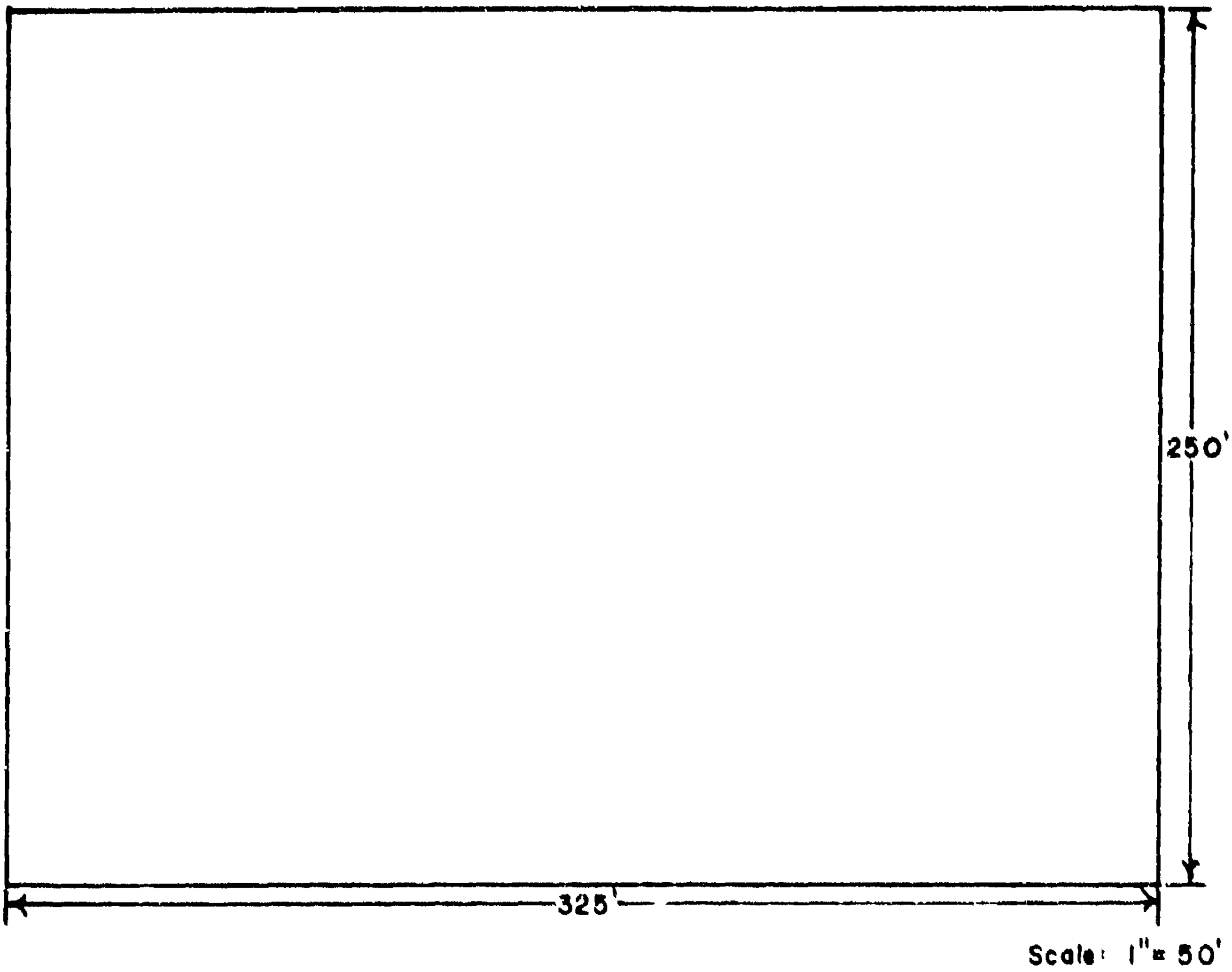
Construction: Fire Resistive
Height: 1 story, 20 ft.
Area: 89,600 sq. ft.
Protection: Automatic Sprinklers

Figure 6.4 Mattress Factory



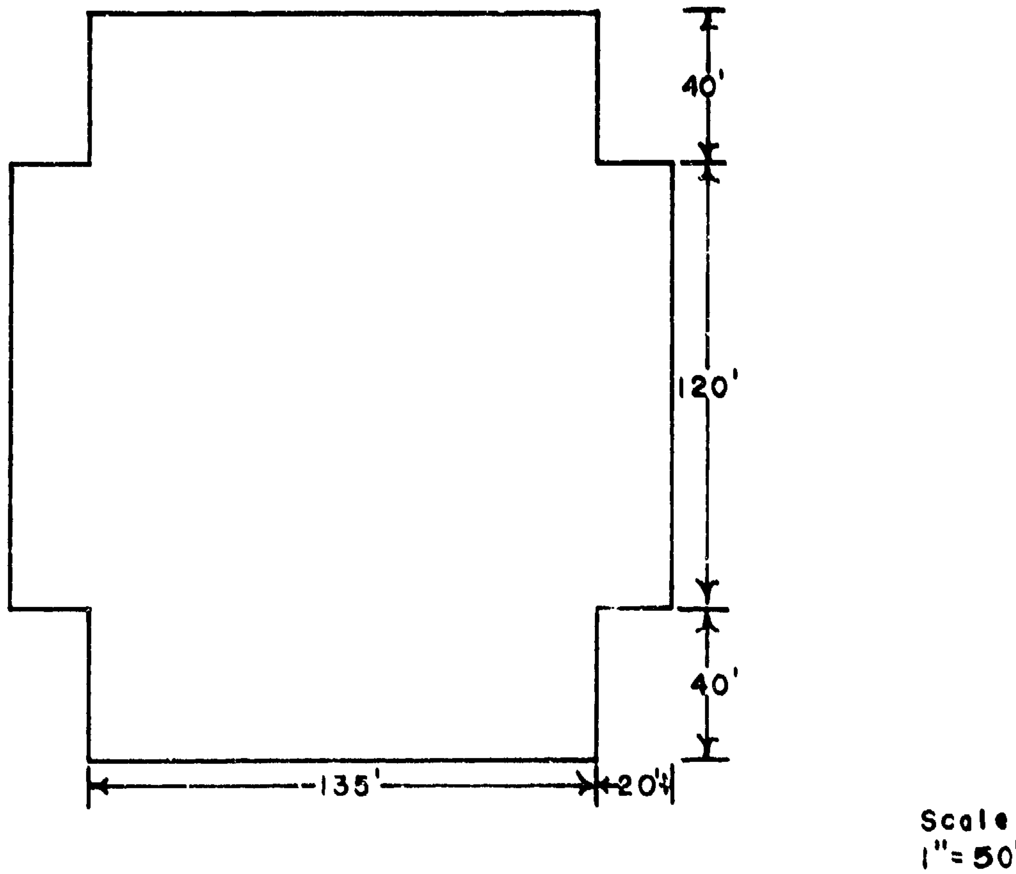
Construction: Protected Non-Combustible
Height: 3 stories, 45 ft.
Area: 30,000 sq. ft. per floor
Protection: None

Figure 6.5 Department Store



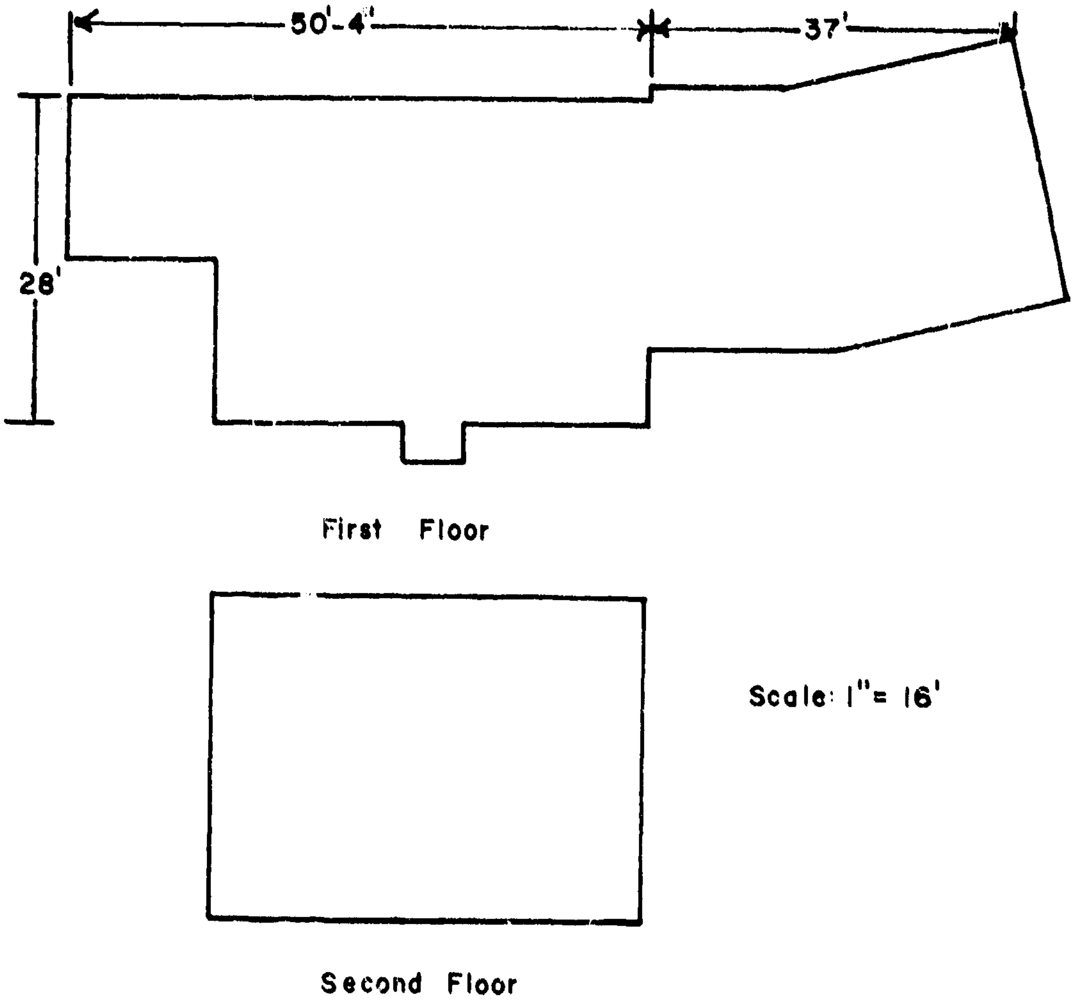
Construction: Unprotected Non-Combustible
Height: 1 story, 15 ft.
Area: 81,250 sq. ft.
Protection: Automatic Sprinklers

Figure 6.6 Library



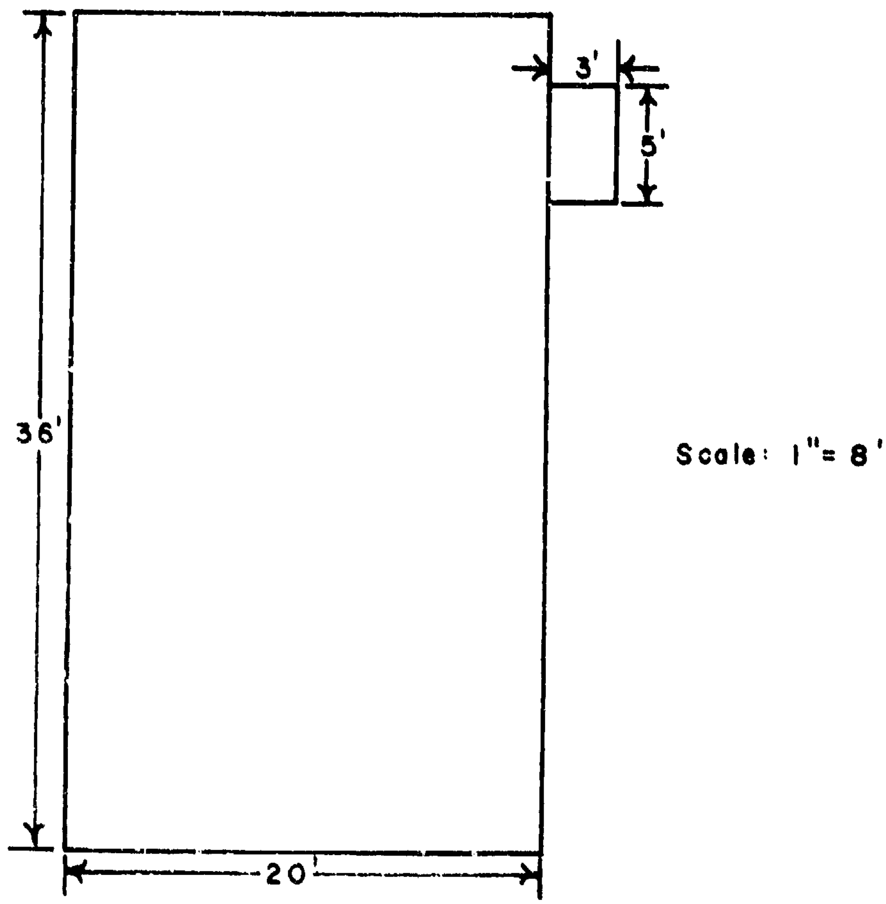
Construction: Fire Resistive
Height: 4 stories, 50 ft.
Area: 28,196 sq. ft. per floor
Protection: None

Figure 6.7 Detached Single Family Dwelling



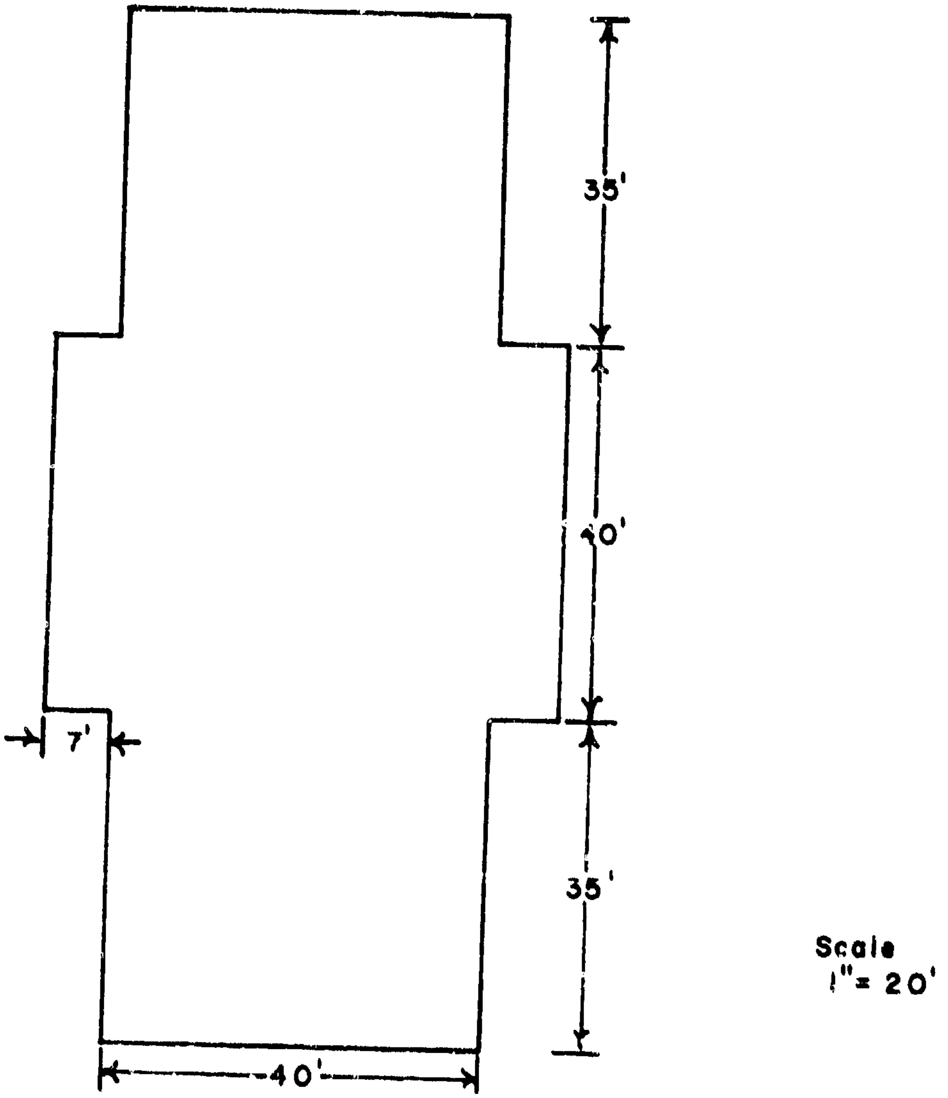
Construction: Wood Frame
Height: 2 stories, 25 ft.
Area: 2980 sq. ft.
Protection: None

Figure 6.8 Townhouse



Construction: Wood Frame
Height: 2 stories, 25 ft.
Area: 720 sq. ft. per floor
Protection: None

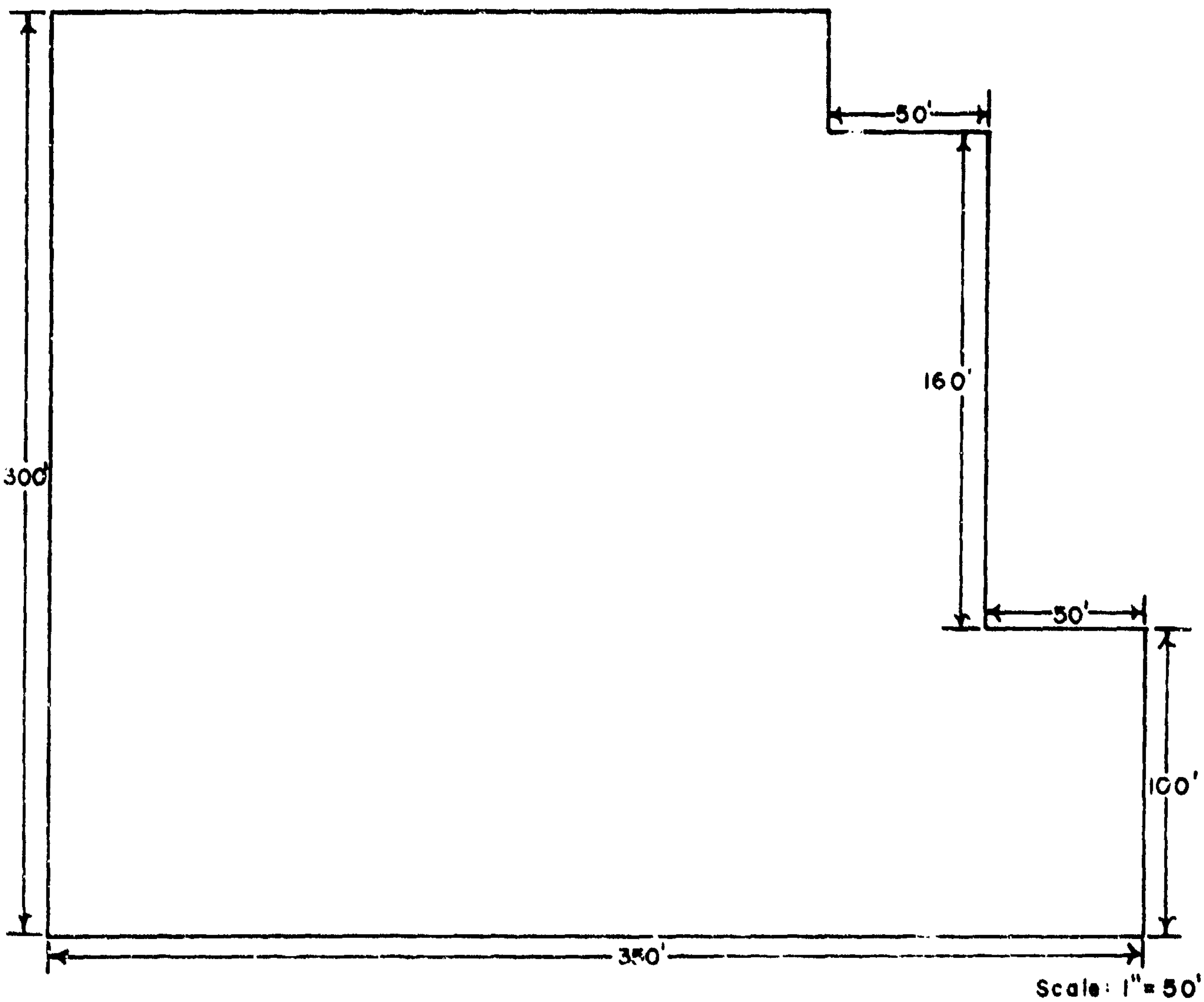
Figure 6.9 Garden Apartment



Construction: Ordinary
Height: 3 stories, 35 ft.
Area: 4,400 sq. ft. per floor*
Protection: None

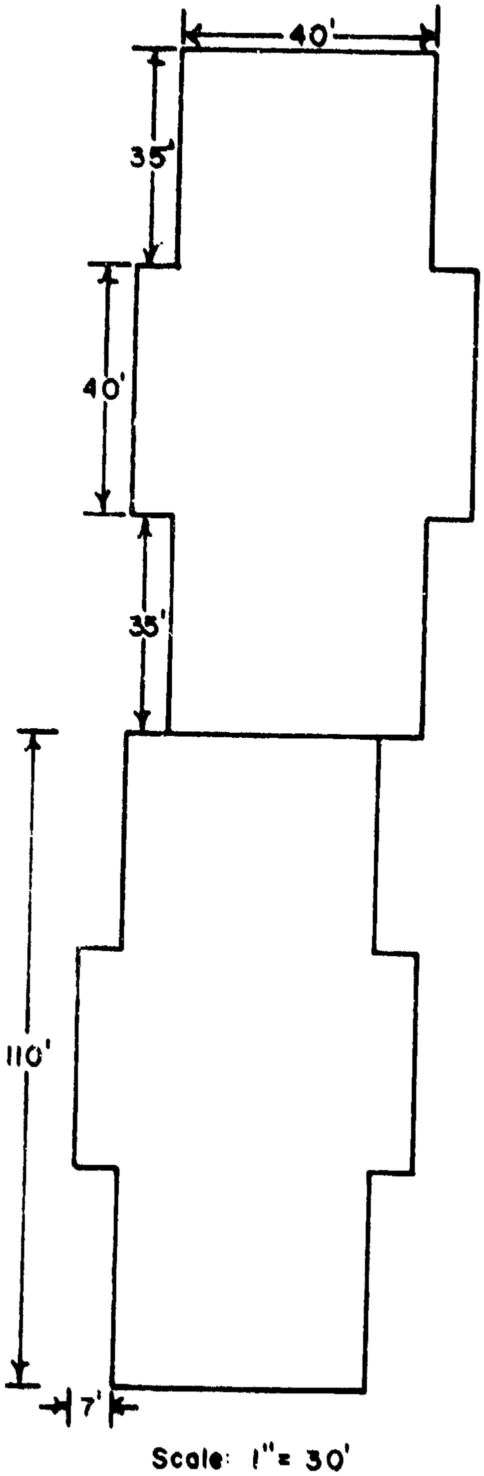
*1,400 sq. ft. per fire area

Figure 6.10 Rolled Paper Warehouse



Construction: Protected Non-Combustible
Height: 3 stories, 40 ft.
Area: 105,000 sq. ft. per floor
Protection: Automatic Sprinklers

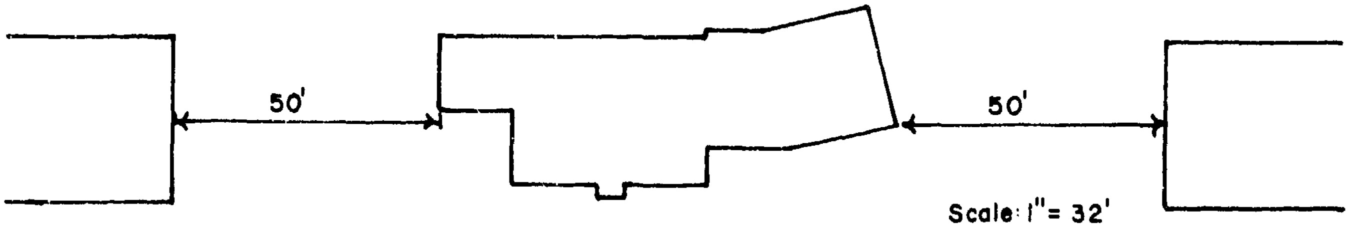
Figure 6.11 High Density Residential Complex



Construction: Ordinary
Height: 3 stories, 35 ft.
Area: 4,400 sq. ft. per floor*
Protection: None
Exposure: 0 ft.

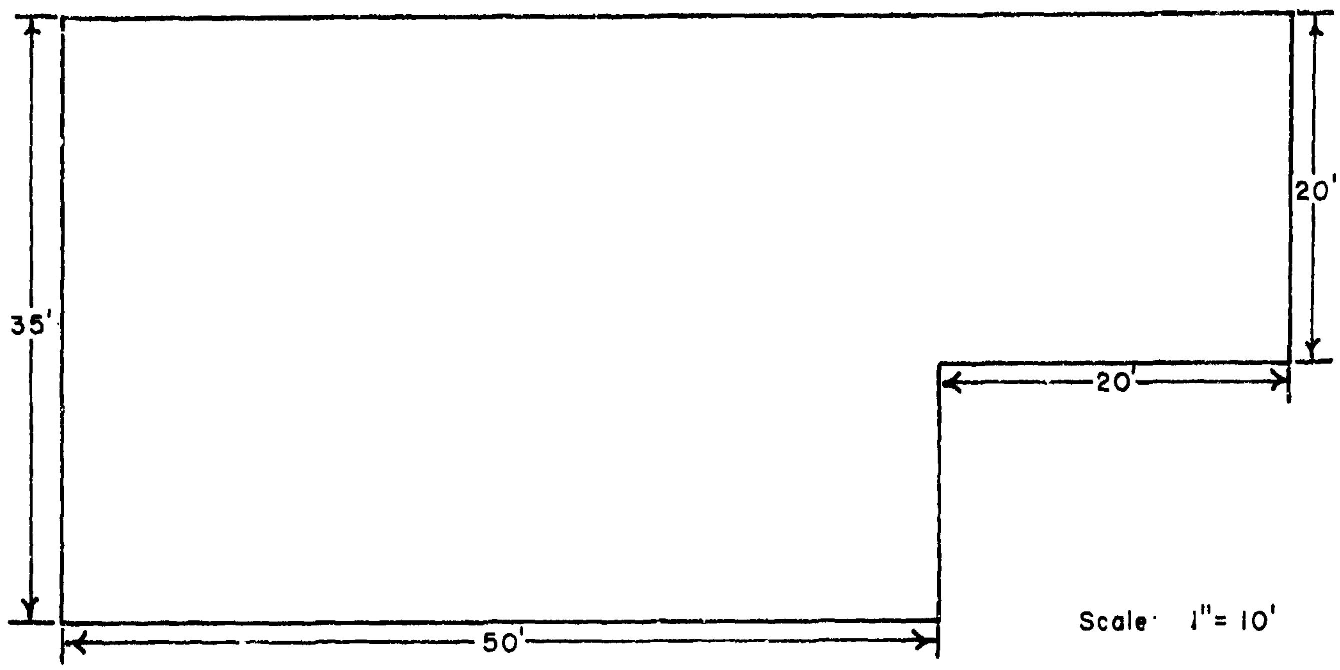
*1,400 sq. ft. per fire area

Figure 6.12 Medium Density Residential Complex



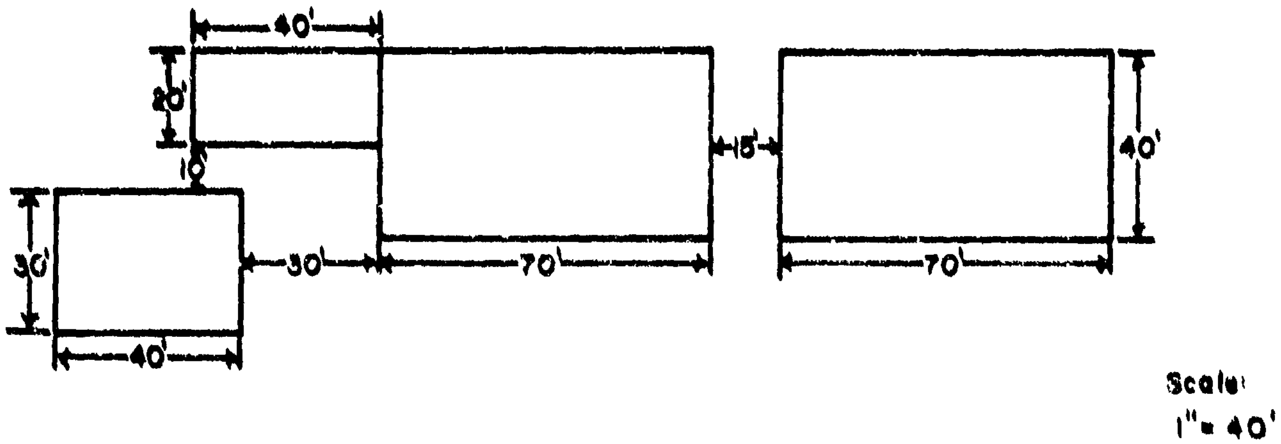
Construction: Wood Frame
Height: 2 stories, 25 ft.
Area: 2,980 sq. ft.
Protection: None
Exposure: 50 ft.

Figure 6.13 Low Density Residential Complex



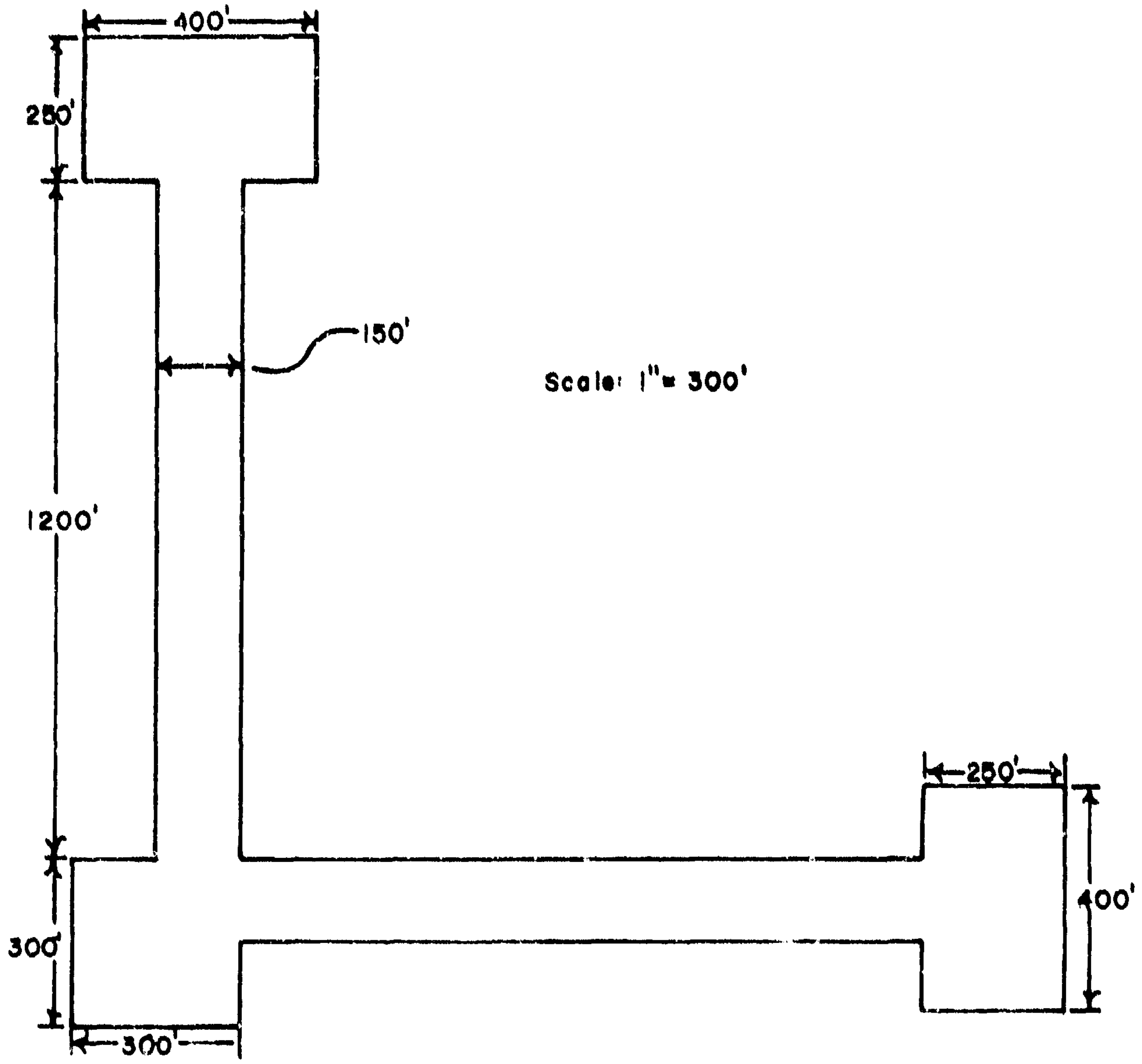
Construction: Wood Frame
Height: 2 stories, 25 ft.
Area: 1,950 sq. ft. per floor
Protection: None
Exposure: Over 150 ft.

Figure 6.14 Detached Commercial Complex



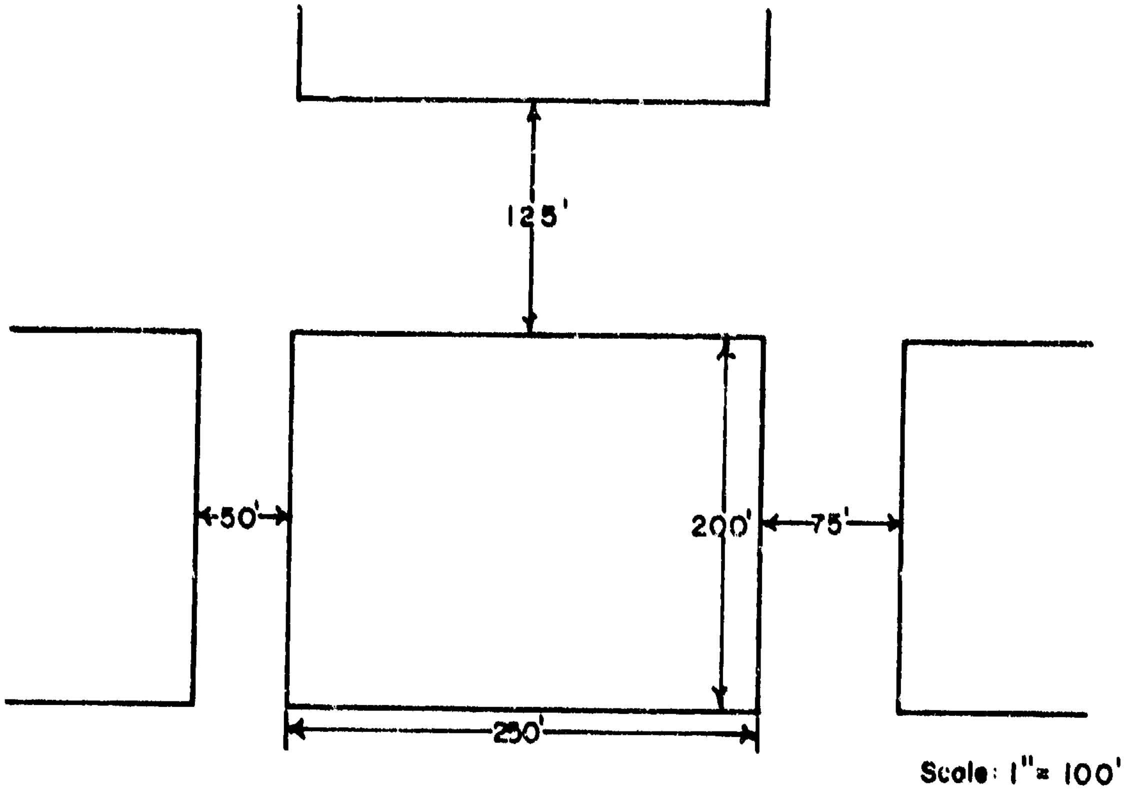
Construction: Unprotected Non-Combustible
Height: 1 story, 15 ft.
Area: 2,800 sq. ft. for fire area
Protection: None
Exposure: 0 ft. and 15 ft.

Figure 6.15 Shopping Center



Construction: Fire Resistive
Height: 2 stories, 30 ft.
Area: 100,000 sq. ft. per floor for fire area
Protection: Automatic Sprinklers
Exposure: 0 ft.

Figure 6.16 Industrial Park



Construction: Unprotected Non-Combustible
Height: 1 story, 15 ft.
Area: 50,000 sq. ft.
Protection: None
Exposure: 50', 75' and 125'

Table 6.1 Fire Flow Requirements for the Selected Occupancies and Complexes.[1]

Buildings	IITRI	ISO	ISU	PFRB	Theory
Hospital	1750	1500	590	1000	680
High Rise Office	3220	1500	1500	1000	1800
Furniture Warehouse	*	2750	21500	2250	13200
Mattress Factory	900	4250	3600	2250	4170
Department Store	*	2000	12190	2750	11000
Library	1510	1750	3383	1250	3930
Detached Single Family Dwelling	690	1000	360	750	420
Townhouse	530	750	260	750	210
Garden Apartment	520	1750	170	750	200
Rolled Paper Warehouse	*	6000	37800	4500	15300
Complexes					
Hi-Density Residential	520	2000	170	750	200
Medium-Density Residential	690	1250	360	750	420
Low-Density Residential	660	1250	520	750	590
Detached Commercial	*	1500	340	750	450
Shopping Center	*	2750	12060	4000	13560
Industrial Park	*	4000	6000	2250	6850

*Area exceeds maximum permitted for application of technique.

[1]Fire flows are presented in units of gallons per minute.

The ISO technique produces either the highest or lowest fire flow requirement for 11 of the 16 selected buildings and complexes. Application of the ISU technique results in 10 highest or lowest requirements for a given building or complex. The ISU technique and the Theory appear to have relatively similar results for the 16 cases.

6.3 Water Supply for Domestic Requirements

It has been established that community water demand is a function of consumer requirements and fire protection requirements. The previous section depicts the projected water demand for fire protection. Using the same building examples this section applies the instantaneous flow demand criteria established in Section V for consumer demand. This information is presented in Table 6.2 according to the respective building codes.

Analysis of Table 6.2 clearly indicates that the consumer consumption demand is relatively small when compared to the fire flow demand. It should be further noted that the area complex example sited in Section V only indicated an instantaneous flow demand of 214 gallons for several buildings. Based upon current findings it appears that if fire flow demand is met in a designated demand area, consumer consumption will also be met.

Table 6.2

Domestic Water Supply Requirements for Case Study Occupancy Classifications

Occupancy		Building Code: BOCA	AIA	SBCC	ICBO
Hospital	MA:	61,560	18,000	48,000	22,600
	GPM	615.6	180	480	226
High Rise Office	MA:	21,546	72,000	------	60,000
	GPM	43.00	144.0	------	120.0
Warehouse	MA:	84,800	40,000	180,000	21,000
	GPM	21.2	10.0	45.0	5.25
Mattress Factory	MA:	84,000	24,000	46,000	13,200
	GPM	21.0	6.0	11.5	3.3
Department Store	MA:	109,440	40,000	67,500	21,000
	GPM	82.1	30.0	50.6	15.8
Library	MA:	84,500	40,000	12,000	15,800
	GPM	6.4	3.0	1.0	2.0
Single Family Dwelling	MA:	24,480	36,000	72,000	-------
	GPM	29.4	43.2	86.4	-------
Townhouse	MA:	24,480	36,000	52,000	-------
	GPM	58.7	86.4	124.8	-------
Garden Apartment	MA:	24,480	36,000	52,000	15,800
	GPM	88.1	129.6	176.2	60.3
Rolled Paper Storage	MA:	84,800	40,000	72,000	16,000
	GPM	7.0	3.3	6.0	1.3

KEY: MA = Maximum Area
GPM = Gallons Per Minute

Occupancy		BOCA	AIA	SBCC	ICBO
High Density Residential Complex	MA:	24,480	36,000	72,000	15,800
	GPM:	130.0	152.0	224.0	94.0
Moderate Density Residential Complex	MA:	24,480	36,000	72,000	------
	GPM:	91.0	99.0	136.0	------
Low Density Residential Complex	MA:	24,480	36,000	72,000	------
	GPM:	30.0	45.0	49.0	------
Detached Commercial	MA:	109,440	40,000	67,500	21,000
	GPM:	1100.0	400.0	675.0	210.0
Shopping Center	MA:	109,440	40,000	67,500	21,000
	GPM:	219.0	80.0	135.0	42.0
Industrial Complex	MA:	109,440	40,000	67,500	21,000
	GPM:	547.0	200.0	338.0	105.0

VII. CONCLUSIONS AND DIRECTIONS FOR FUTURE WORK

This study evaluates the water supply requirements for buildings and structures with specific reference to both model building code and civil preparedness criteria. The study outlines a systematic approach to thoroughly examine water discharge rates for achieving the water demand requirements for domestic use and fire protection.

Conclusions

In section II, a theoretically-based method is suggested. The method is outlined in steps to reduce the inherent complexity of the method.

Existing methods utilized to calculate fire flow requirements are reviewed in section III. The review criteria consisted of the internal validity, external validity and utility of the method. From this review, the four most appropriate methods are selected for further use and evaluation.

In section IV, the water distribution and sewer systems in Warsaw, New York are analyzed relative to their adequacy under crisis relocation conditions relative to domestic use and fire protection. The water available for fire protection is determined relative to various domestic demands and observed to be severely inadequate at peak domestic demands.

The interaction of model building code criteria on water supply requirements for domestic and fire protection usage is examined in section V. The four model building codes are observed to influence the water supply requirements as a function of the maximum height and areas of buildings, permitted by the codes. Water demand requirements for fire protection are compared to those for domestic requirements and observed to generally be significantly greater than the domestic needs.

Sixteen specific case occupancies and complexes are analyzed in section VI relative to water demand requirements. As in section V, fire protection water

requirements are indicated as being significantly greater than domestic water requirements.

Directions for Future Research

This report addresses the issue of water supply requirements. The state-of-the-art in calculating water supply requirements is observed to be lacking a strong, valid theoretical or empirical basis, especially relative to fire protection. A theoretical approach is presented as a result of this deficiency.

The theoretical approach developed in section II and utilized in the analyses presented in sections V and VI requires further analysis to validate the method. Several limitations and assumptions are noted throughout section II, all of which require detailed examination, e.g., the effectiveness of the water discharged onto a fire relative to impingement on the fire and conversion to steam.

Calculation techniques for evaluating the domestic demand also appears to be deficient.

The water supply of a community must be sufficient to meet the following four demands: domestic, industrial, commercial and public. Several factors are known to influence the amount of water used in non-emergency situations such as climate, affluence of the community, etc. Several factors are also recognized to influence the amount of water required to provide an adequate level of safety in emergency conditions, e.g. fire protection. Surveys have been conducted to examine the amount of water utilized in a community in non-emergency and emergency situations. Despite this available information, the state-of-the-art in designing appropriate water supply systems for a community appears to lack technical sophistication.

Current requirements for water supply which lack a sound technical basis

can induce under- or over-design. Currently, a particular design for a water supply system can only be evaluated by an in-service analysis of that system. If such an analysis indicates under- or over-design in the system after installation of the system, corrections can be costly. Thus, the state-of-the-art in demand requirements for water supply can lead to non-cost-effective designs.

In section IV, this report notes the severe inadequacy of water for fire protection during peak demand periods. This condition should be examined in more communities considered to be potential host communities to investigate whether this inadequacy is typical or atypical.

From the analyses in sections IV, V and VI, the fire protection requirements are consistently greater through the domestic consumption requirements. The following question should be addressed concerning the adequacy of the water demand requirements for domestic consumption and fire protection:

Is there sufficient water available for fire protection with:

a) domestic use excluded

b) average domestic use considered

c) maximum domestic use considered.

Appropriate strategies should then be proposed so that water is available for the community needs. Possible strategies may include a public education program relative to the problem, requesting the public to limit or curtail domestic consumption during major fire incidents or the establishment of a standard operating procedure relative to fire suppression activities, such that water is not "wasted" on structure fires which result in the destruction of the building beyond a "salvageable" point. Other strategies may consider the provision of an alternative water supply source to supplement the axisting system in the community.

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APPENDIX

Reviews of the Calculation Techniques for Fire Flow

BALL & PIETRZAK

Ball, J.A. and Pietrzak, L.M., "A Computer Simulation to Estimate Water Application Effectiveness in Suppression of Compartment Fires", Presented at the Fall Technical Meeting of the Eastern Section/Combustion Institute, November 18-19, 1976.

General Discussion: The Fire Demand Model developed by Ball & Pietrzak considers a post-flashover, single compartment fire. The fire character is assessed through an analysis of building and fuel parameters. The success or failure of a specific suppression effort is then predicted by an analysis of the fire character versus the suppression effort. The extinguishment criteria used are: 1) the heat of water vaporization must be greater then the heat generation rate by charring combustion and, 2) the temperature of the gas and the wall/ceiling in the compartment.

The computer model is based on theoretical analyses of the characteristics of fuel or ventilation controlled compartment fires and the extinguishment characteristics of water. The model performs these analyses of the characteristics at particular time intervals, reiterating until the fire is concluded to be extinguished.

Internal Validity: Sources for the theoretical analysis are identified and appear to have been utilized within the limitations of those sources. Assumptions, procedures and conclusions all appear appropriate.

External Validity: The model is applicable to an analysis of water needed for extinguishment in a particular compartment. Proper definition and selection of a compartment could allow this model to be used for a large majority of applications. Use of this theoretical model produces fire flows slightly greater than those found necessary in laboratory experiments by Salzberg, Vodvarka and Maatman, which were about one-half of those used on actual fires. Thus, this model appears to predict fire flows within the difference between laboratory and actual fire application.

Utility: A computer is essential for utilization of this model. Further, proper water application rates must be determined through trial and error if this model is utilized, i.e. a particular water application rate is observed to be successful or unsuccessful and does not indicate the amount of excess or deficient flow.

BENGSTON

Bengtson, Staffan, "The Effect of Different Protection Measures with Regard to Fire-damage and Personal Safety". Fou-Brand, SFPA, Sweden, #1, 1978.

General Discussion: The equations for fire flow are based on papers by Baldwin and Thomas, which are then revised for "Swedish conditions and expanded for different occupancy hazards." Baldwin found that the rate of water (gpm) needed to extinguish actual fires was 1.21 x $A^{0.664}$ where A is the fire area. The coefficient, 1.21, is adjusted to account for different tactics used by Swedish Fire Brigades, requiring less water. The resulting equations are:

occupancy hazard	fire flow (gpm)
low	$.06\ A^{0.664}$
medium	$.29\ A^{0.664}$
high	$1.36\ A^{0.664}$

Internal Validity: The base equation is identified, however, justification for the adjustments are not presented, other than it being revised for "Swedish conditions." Previously, there was no distinction for hazard, in the equation which is now present in this technique. Except for the lack of justification of the revised constants, all other assumptions, procedures and conclusions appear acceptable.

External Validity: These equations are applicable for all occupancies within Sweden. Extension of the application to other countries does not appear appropriate because of the special adjustments for Sweden.

Utility: The equations can be readily used, with a portable calculator required because of the exponent. Otherwise, the equations are not too complex. Knowledge of the fire area and hazard of the occupancy are the only prerequisites for use.

CORLETT & WILLIAMS

Corlett, R.C. and Williams, F.A., "Modeling Direct Suppression of Open Fires," Paper presented at the 1975 Fall Meeting of the Western States Section of the Combustion Institute, Stanford Research Institute, Menle Park, California, October 20-21, 1975.

General Discussion: The technique presented by Corlett & Williams is strongly theoretically based. "Open Fires" are considered in this technique, e.g. outdoor fires or fuel-control fires. Extinguishment is based on a critical Froude number, which is a fluid mechanics parameter corresponding to the flames being self-sustaining and not decaying. This analysis considers the heat release rate and the heat feedback to the unburnt fuel.

Internal Validity: Sources for the theoretical foundation are identified. Assumptions, procedures and conclusions are appropriate.

External Validity: This technique is applicable mostly for outdoor fires. Many indoor fires will be ventilation controlled and outside of the scope of this technique.

Utility: Data is not readily available for use in this technique. Values for the critical Froude number have not been identified, nor have many of the parameters needed in the equations been calculated for a wide range of applications.

FIA

Factory Insurance Association, "Attachment to Engineering Council Minutes," April 24-27, 1961, (unpublished).

General Discussion: This technique concentrates on the adequacy of water supplies for mostly industrial occupancies. The criteria depend on the fire area and hazard of the occupancy. The water supply requirements is divided into two segments - water needed for sprinklers and water for hose streams. The requirements are determined from the use of appropriate graphs.

Internal Validity: Water supply requirements were established by surveying 45 engineers for their judgments on the topic.

External Validity: This procedure is applicable only to sprinklered properties.

Utility: The technique is easily used, requiring only interpretation of the graphs and an assessment of the hazard and largest fire area.

HUTSON

Gage, Babcock and Associates, "Study Report on UBC-UFC Changes Proposing Building Regulation Based on Water Supply and Fire Department Capabilities", Unpublished report for National Forest Products Association, Washington, D.C., January, 1977.

General Discussion: This calculation procedure was developed by A.C. Hutson from his judgment. The procedure considers the area and height of the building, construction type, occupancy hazard, sprinkler and other fire protection equipment and size of the fire department. A range of acceptable values for presented for credits and charges, requiring a large degree of judgment in determining specific values.

Internal Validity: The method was apparently based totally on "professional judgment", using no specific technical resources.

External Validity: The method is applicable for all buildings and does not appear to be contradictory.

Utility: Data is not readily available for this procedure, requiring professional judgment. Only low analytical skills are needed for application of the procedure.

ICBO

International Conference of Building Officials, "Proposed Code Change to Uniform Building Code and Uniform Fire Code," Unpublished Report by Western Fire Chiefs Association, December 3, 1975.

General Discussion: A method for calculating fire flow was proposed for changes to the Uniform Building and Fire Code Committees. The fire flow would consider the fire area, exposure hazard and hazard classification. The intent of the change was to replace maximum areas of buildings and fire zones requirements with requirements of an adequate water supply and fire suppression manpower to be capable of delivering the needed fire flow for a particular building.

Internal Validity: Data sources, assumptions and procedures are not noted for formulation of exposure and hazard factors which are used to adjust the area of the building with the resultant quantity somehow related to the required flow.

External Validity: Inclusion of the proposed changes with the remainder of the code results in contradictions, e.g. the maximum allowable area of the building may be increased by sprinkler protection, however, fire flow can not be adjusted by sprinklers, resulting in an area higher than allowed by the fire flow. Comparison with the ISO technique illustrates that this proposed change produces requirements for significantly higher fire flows.

Utility: The technique is readily applied requiring few analytical skills. Data needed for the technique is readily available.

IITRI

Salzberg, Frederick, Fire Department Operations Analyses, Illinois Institute of Technology Research Institute, for Office of Civil Defense, Washington, D.C., 1970.

General Discussion: Data was collected from 134 fires in several occupancy types in the Chicago area to determine the water application rate needed for control, as a function of fire area. Reported fires were of differing levels of magnitude, so as not to solely concentrate on the large-loss fires. Water application rates for the studied fires was calculated through a knowledge of length and diameter of hose utilized and calculated nozzle pressure.

The fire flow, G, is calculated by one of the following equations:

1) Residential Occupancies:

$$G = 9 \times 10^{-5} A^2 + 50 \times 10^{-2} A$$

2) Non-Residential Occupancies:

$$G = 1.3 \times 10^{-5} A^2 + 42 \times 10^{-2} A$$

These equations were obtained through curve-fitting of the available data points.

The investigation noted that tactical procedures can greatly influence the application rate of water utilizing, e.g. interior versus exterior attack, leading-off with large diameter rather than small diameter hose, etc. 21 laboratory experiments on use of manual streams to extinguish compartment fires were also reported, for comparison purposes. Analysis of this experiment indicated that firefighter training and comfort were key parameters in determining the amount and rate of water used and the observed application rates by IITRI of the 134 actual fires was approximately double the rate used in the laboratory.

Internal Validity: Data is collected from fire incidents of various magnitudes, in various occupancy types. Assumptions, procedures and conclusions appear to all be appropriate. Data from more fire incidents would help to validate this technique.

External Validity: Because of the use of various magnitudes and not those considered to be "worst cases", resultant fire flows would be expected to be lower than those from other equations (however this is not the case).

Utility: The equations can be readily used, only requiring a knowledge of the occupancy type and potential fire area. Calculation can be performed with or without the use of a portable calculator.

ISO

Insurance Services Office, "Guide for Determination of Fire Flow", ISO, New York, December, 1974.

General Discussion: An equation for fire flow was developed after an analysis of the estimated amount of water utilized on 1,450 actual fires. These fires were contained only in ordinary type construction buildings and were fully-developed. The data was taken from fire departments throughout the country, thus varying fire suppression tactics were accounted for in the "curve-fitting" process. The resulting equation is:

$$G = 18\ C\ (A)^{0.5}$$

where C is related to the construction type and A is the area of the building. The required flow, G, is adjusted for occupancy hazard, presense of sprinkler protection and exposure hazards.

Internal Validity: The data source was identified as 1,450 fire reports. The accuracy of the measurement of water usage by the fire departments is questioned, thereby questioning the validity of the data. Assumptions and procedures utilized appear to be proper.

External Validity: The equation is applicable to all buildings and does not appear to be contradictory.

Utility: The equation is easily used, with data being readily available and the calculation being simplistic in nature.

Roger, Keith and Nelson, F.W., "Water for Fire Fighting", Iowa State University Bulletin, Vol. LXV, No. 18, 1967.

General Discussion: This technique for computation of fire flow, G, is:

$$G = \text{Volume of space} \div 100$$

This equation was derived after a study of compartment fires and performance of several experiments. The equation is based on combustion in a compartment being dependent on the available oxygen supply and the vaporization of water into stream. The expansion ratio of water to steam is considered to assess the capability of vaporizing water to displace oxygen. Time-temperature curves are analyzed to determine optimal rates of water application, for which steam generation will be a maximum.

Internal Validity: Several Danish studies are referenced for theoretical and statistical bases. Assumptions and procedures appear to be appropriate.

External Validity: This technique appears to be appropriate for well-compartmented buildings because of the dependence on a limited oxygen supply. The technique does not appear to be contradictory.

Utility: The method is easily used, requiring low analytical skills and only a knowledge of the volume of the fire area.

MILKE

Milke, J.A., "A Theoretical Analysis Procedure to Determine Building Fire Flow Estimates", Department of Fire Protection Engineering, University of Maryland, 1976, Unpublished paper.

General Discussion: The technique suggested in this method is theoretically based. The major consideration is absorption of the heat produced by the fire through vaporization of water. The rate of heat release is obtained by dividing the total heat release by the theoretical fire duration. Rate of water application is also determined by the total amount of water required, divided by the theoretical fire duration. An adjustment for potential exposure hazards is also included.

Internal Validity: The sources for the theoretical basis are identified and generally properly used. Incident radiation on exposures is not properly addressed, with the configuration factor not properly computed. The theory utilized on compartment fires is limited to ventilation-controlled fires, which is not identified and cannot be assumed to be the case for all building fires.

External Validity: The technique is applicable only to well-compartmented buildings because of the theory on ventilation-controlled fires. The method does not appear to be contradictory.

Utility: The technique requires some analytical skill, though with the assistance of a portable calculator, calculations can be readily performed. Data is generally available for the method to be readily utilized.

PFRB

Association of Mutual Fire Insurance Engineers, Simplified Water Supply Testing, 2nd Edition, Federation of Mutual Fire Insurance Companies, Chicago, 1958.

General Discussion: The required fire flow is determined using one of two tables. The proper table is selected according to the construction type of the building. Each table relates the ground floor area and height of the building with the occupancy hazard (divided into six classes) and the height of the stored combustibles. The fire flow is given in units of hose streams, which must deliver 250 gpm at 50 psi each.

Internal Validity: Data, assumptions and scientific techniques used for the tabulation are not noted, though the insurance industry typically utilizes loss experience for the development of requirements.

External Validity: The tables are applicable to any building.

Utility: The tables are readily used after an assessment of the size, height and construction type of the building and hazard of the contents.

THOMAS

Thomas, M.A., "The Use of Water in the Extinction of Large Fires, Institution of Fire Engineers Quarterly, July-September, 1959.

General Discussion: This equation for fire flow was developed as a result of a survey of 48 large fires in various areas of the United Kingdom. The equation is:

$$J = 0.1 \sqrt{A}$$

where "J" is the number of hose streams (10 liter/sec) and "A" is the area of the fire compartment in square meters. The fire flow in GPM with 'A' in square feet is:

$$G = 4.76 \sqrt{A}$$

Internal Validity: The data source is identified as the 48 fires. Assumptions and procedures for the statistical analysis appear to be appropriate.

External Validity: This equation was derived for fires in the United Kingdom. The applicability to United States conditions is not known and is questioned because of the large difference in these empirically derived results with those obtained in U.S. fires by ISO and IITRI.

Utility: The equation is easily used with only a knowledge of the fire area as a prerequisite.

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